

**Bacteria TMDL for Tuckahoe Creek,
Little Tuckahoe Creek, Anderson, Broad,
Georges and Readers Branches, and
Deep Run
Henrico, Goochland and Hanover
Counties, Virginia**

Submitted by

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Executive Summary

This report presents the development of a bacteria TMDL for Tuckahoe Creek and its major tributaries, which were listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report and 2002 303(d) Report on Impaired Waters (VADEQ, 1998 & 2002). The Tuckahoe Creek watershed is located in Henrico County in the James River Basin (USGS Hydrologic Unit Code 02080205). The waterbody identification code (WBID, Virginia Hydrologic Unit) for Tuckahoe Creek is VAP-H39R in the Piedmont region of Virginia. There were four separate impaired segment listings in the 2002 303(d) list for the Tuckahoe Creek watershed: Tuckahoe Creek (8.7 mi.), Little Tuckahoe Creek (5.25 mi.), major Tuckahoe Creek tributaries (Anderson, Broad, Georges and Readers Branches, 11.76 mi.), and Deep Run (4.49 mi.). Thus approximately 30.2 miles of Tuckahoe Creek and tributaries were listed as impaired due to a violation of Virginia's water quality standard for fecal coliform bacteria and dissolved oxygen (DO).

The drainage area of the Tuckahoe Creek watershed is approximately 64.3 square miles. The average annual rainfall as recorded at Ashland, VA (within 13 miles of the study area) is 42.20 inches. The approximately 41,200 acre watershed is predominately forested (52.3 percent). Agriculture encompasses 22.0 percent of the watershed, with 5.4 percent cropland and 16.5 percent pasture/hayland. Residential and high use industrial areas compose approximately 19.7 percent of the land base. Transitional use composes 1.5 percent of the watershed. The remaining 4.7 percent of the watershed is comprised of wetlands and open water.

There were **four** separate impaired segment listings in the 2002 303(d) list for the Tuckahoe Creek watershed: major Tuckahoe Creek tributaries (Anderson, Broad, Georges and Readers Branches), Tuckahoe Creek, Little Tuckahoe Creek, and Deep Run.

The major Tuckahoe Creek tributaries Anderson, Broad, Georges and Readers Branches (2002 303(d) Segment ID# VAP-H39R-01) were listed as threatened on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report and 2002 303(d) Report on Impaired Waters (VADEQ, 1998 & 2002) due to violations of the State's water quality standard for fecal coliform bacteria and DO at the mainstem Tuckahoe Creek station 2-TKO004.69.

Tuckahoe Creek (2002 303(d) Segment ID# VAP-H39R-02) was listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report and 2002 303(d) Report on Impaired Waters (VADEQ, 1998 & 2002) due to violations of the State's water quality standard for fecal coliform bacteria and DO. Out of 19 bacteria samples collected during the 1998 assessment period, 5 violated the water quality standard. During the subsequent 2000 assessment period, 8 of 31 samples violated the water quality standard, and during the most recent 2002 assessment period, 6 of 47 samples violated the standard. A total of 99 fecal coliform samples, with 18 water quality standard violations, were taken by DEQ at station 2-TKO004.69 from July 1990 through December 2003. A total of 22 E. coli samples, with 5 water quality standard violations, were taken at the same station between September 2002 through December 2003.

Little Tuckahoe Creek (2002 303(d) Segment ID# VAP-H39R-03) was listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report and 2002 303(d) Report on Impaired Waters (VADEQ, 1998 & 2002) due to violations of the State's water quality standard for fecal coliform bacteria and DO. During the 2000 assessment period, 3 of 13 samples violated the water quality standard. During the 2002 assessment period, 10 of 35 samples violated the standard. A total of 51 fecal coliform samples, with 17 water quality standard violations, have been taken by DEQ at station 2-LIY001.73 from July 1997 through December 2003. A total of 20 E. coli samples, with 12 water quality standard violations, have also been taken at the same station from March 2000 through December 2003.

Deep Run (2002 303(d) Segment ID# VAP-H39R-04) was listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report and 2002 303(d) Report on Impaired Waters (VADEQ, 1998 & 2002) due to violations of the State's water quality standard for fecal coliform bacteria and DO. During the 2000 assessment period, 8 of 18 samples violated the water quality standard. During the

2002 assessment period, 18 of 41 samples violated the standard. A total of 57 fecal coliform samples, with 22 water quality standard violations, have been taken by DEQ at station 2-DPR002.46 from July 1997 through December 2003. A total of 21 *E. coli* samples, with 7 water quality standard violations, have also been taken at the same station from March 2000 through December 2003.

An upstream station on Tuckahoe Creek at Rt. 250, 2-TKO010.64, was sampled from July 1997 to April 2001. A total of 43 fecal coliform samples, with 4 water quality standard violations, were taken by DEQ at station from July 1997 through April 2001. From these results at less than a 10 percent violation rate, the upper portion of mainstem Tuckahoe Creek above Little Tuckahoe Creek was removed from the 303(d) segment in the 2002 assessment.

According to Virginia Water Quality Standards (9 VAC 25-260-10A), "all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)."

As indicated above, Tuckahoe Creek must support all designated uses and meet all applicable criteria. Tuckahoe Creek does not currently support primary contact recreation.

The load-duration approach is used to develop the TMDL for the study watershed.

The assessment of bacterial sources involves estimating loads from various sources in the watershed. It was accomplished by determining the relative contribution by these sources using Bacterial Source Tracking (BST) methodology. A total of 12 ambient water quality samples were collected on a monthly basis from September 2002 through August 2003 at 2-TKO004.69 for BST analysis. The results indicate that the majority of bacteria are coming from anthropogenic sources. Four categories of sources were considered: human, pet, livestock and wildlife. The analyses determined the relative contribution of all bacteria by these sources. The data indicated that on an average basis, relative contributions of bacteria are – 12% by human, 39% by pet, 28% by livestock, and 20% by wildlife. Fecal and *E. coli* bacteria were also enumerated as part of the BST analyses.

The bacteria loads in the study watershed were calculated for point and non-point sources, because there were two possible permitted bacterial point source discharges in the watershed. One was aMS4 permit for which EPA requires a waste load allocation be estimated. For non-point sources (human, pets, livestock, and wildlife) total annual fecal productions were calculated separately. Data on population density and waste production by septic systems, pets, livestock and wildlife were collected from various sources, and total fecal productions were calculated with appropriate unit conversions.

The load-duration method essentially uses an entire stream flow record to provide insight into the flow conditions under which exceedances of the water quality standard occur. There was no gaging station on Tuckahoe Creek. Therefore, the flow-duration curve using historical flow data collected at the USGS gaging station Deep Creek near Mannboro, VA (#02041000) was developed. The load-duration curve for Tuckahoe Creek was then developed by multiplying each flow level along the flow-duration curve by the applicable water quality standard and required unit conversions. Each water quality observation is then assigned to a flow interval by comparing the date of each water quality observation to the flow record of the reference stream. The stream flow from the date of the water quality observation is then used to calculate a stream flow and flow-duration interval for the stream. The loads on the load-duration curve are multiplied by 365 days/year to determine the annual loads. Fecal coliform data was converted to *E. Coli* using a translator equation developed based on the data sets from the DEQ's statewide monitoring network. The observed loads were plotted on the load-duration curve to determine the number and pattern of exceedances of water quality standards.

Exceedances of the water quality standard occurred under all flow conditions. The highest exceedance of the water quality standard occurred at low flows (94% flow interval at 2.40 cfs). This represents the flow condition under which the largest bacteria reduction is required in order to meet water quality standards. The translated load at this flow was 1.55×10^{14} cfu/yr. Under the instantaneous *E. coli* standard of 235 cfu/100mL, these loads would have to be reduced by 97% to an allowable load of 5.03 x

10^{12} cfu/yr. The allowable load is simply the *E. coli* standard multiplied by the applicable flow condition and the proper unit conversions.

For the Tuckahoe Creek watershed, the average annual *E. coli* load is 4.60×10^{15} cfu/yr, and the TMDL under average annual flow conditions is 1.50×10^{14} cfu/yr. These values are used to calculate required reductions. There were two dischargers given wasteload allocations. Henrico County Water Treatment Plant VA0091197 was given a fecal bacteria load allocation for occasional discharges of 1.22×10^{12} cfu/yr. The Henrico MS4 wasteload allocation was determined to be 1.05×10^{13} cfu/yr. These two WLAs were totaled for the total point source wasteload allocation of 1.17×10^{13} cfu/yr. Therefore, the load allocation would be determined by subtracting the waste load allocation (1.17×10^{13} cfu/yr) from the TMDL load (1.50×10^{14} cfu/yr), yielding a LA of 1.38×10^{14} cfu/yr. This is presented in Table E1.

Table E1. TMDL and required reduction for Tuckahoe Creek

Allowable Loads (cfu/yr)		Average Annual EC Load (cfu/yr)	Required Reduction
TMDL annual average	1.50×10^{14}		
Wasteload Allocation (WLA)	1.17×10^{13}		
MOS	(implicit)		
Load Allocation	1.38×10^{14}	4.60×10^{15}	97.00%

The Tuckahoe Creek TMDL development presented in this report is the first step toward the attainment of water quality standards. The second step is to develop a TMDL implementation plan, and the final step is the field implementation of the TMDL to attain water quality standards.

The Commonwealth intends for this TMDL to be implemented through a process of phased implementation of best management practices (BMPs). The development of the Tuckahoe Creek TMDL requires a 97% reduction in non-point source loading in order to attain a 0% violation of water quality standards. In order to evaluate interim reduction goals for a phased implementation plan, several reduction levels (80%, 70%, and 58%) and their associated violation rates were assessed. Reduction curves similar to the maximum exceedance/reduction curve were plotted and are presented in this report.

Based on the reduction analysis presented above and a goal of 10% or fewer violations of the water quality standard, a suitable Phase I reduction level would be 70%, which resulted in an 8.8 percent violation rate. Table E2 presents the Phase I load allocations based on a 70% reduction of in-stream loads.

Table E2. Phase I Load Allocations (based on a 70% reduction)

	Total (cfu/yr)	Human @ 12% (cfu/yr)	Pet @ 39% (cfu/yr)	Livestock @ 28% (cfu/yr)	Wildlife @ 20% (cfu/yr)
Average Annual Load	4.60×10^{15}	5.52×10^{14}	1.79×10^{15}	1.29×10^{15}	9.20×10^{14}
Reduction	70%	98%	95%	72%	0%
Allowable Annual Load	1.38×10^{15}	1.10×10^{13}	8.95×10^{13}	3.61×10^{14}	9.20×10^{14}

Phase I load reduction percentages are proposed for human, pet and livestock contributions. This phase I scenario proposes a 98% reduction in the human *E. coli* load, a 95% reduction in the pet *E. coli* load, and a 72% reduction in the livestock *E. coli* load. Virginia and EPA are not proposing the elimination of

wildlife to allow for the attainment of water quality standards. The reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

In order to provide some insight into the nature of the Tuckahoe Creek water quality violations and to better target possible BMPs, the correlation between violations, stream flow change, and local precipitation was examined. Results suggest that as many as 100 percent of the violations could be related to runoff events. This suggests that a large majority of the E. coli violations may be caused by non-point source runoff events. Among some of the BMPs effective in reducing bacteria runoff from such precipitation events include: riparian buffers zone, retention ponds/basins, range and pasture management, and animal waste management. Detailed lists of BMPs and their relative effectiveness will be included in the eventual TMDL implementation plan for the watershed.

The development of the Tuckahoe Creek TMDL was not possible without public participation. A Technical Advisory Committee meeting was held at the Piedmont Regional Office training room in Glen Allen, VA at 2 pm on January 14, 2004. A public meeting was held at the Piedmont Regional Office of DEQ, 4949-A Cox Road, Glen Allen, VA. at 7 pm on January 20, 2004 to discuss the process for TMDL development and the source assessment input for Tuckahoe Creek. Twelve people attended the public meeting. Copies of the presentation materials were available for public distribution. The public meeting was public noticed in the Virginia Register. There was a 30 day-public comment period after the public meeting. Four questions were asked at the public meeting, and one written comments were mailed to DEQ. These questions, comments and responses are submitted to EPA separately from this document.

1. Introduction

Section 303(d) of the Clean Water Act and US Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies which are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and non-point sources to restore and maintain the quality of their water resources (EPA, 1991).

The Commonwealth of Virginia's (Virginia's) 1997 Water Quality Monitoring, Information, and Restoration Act (WQMIRA) codifies the requirement for the development of TMDLs for impaired waters. Specifically section § 62.1-44.19:7 C states:

"The plan required by subsection A shall, upon identification by the Board of impaired waters, establish a priority ranking for such waters, taking into account the severity of the pollution and the uses to be made of such waters. The Board shall develop and implement pursuant to a schedule total maximum daily loads of pollutants that may enter the water for each impaired water body as required by the Clean Water Act. "

The EPA specifies that in order for a TMDL to be considered complete and approvable, it must include the following eight elements:

1. It must be designed to meet applicable water quality standards,
2. It must include a total allowable load as well as individual waste load allocations and load allocations,
3. It must consider the impacts of background pollution,
4. It must consider critical environmental conditions or those conditions (stream flow, precipitation, temperature, etc.) which together can contribute to a worst-case exceedance of the water quality standard,
5. It must consider seasonal variations which together with the environmental variations can lead to a worst-case exceedance,
6. It must include an implicit or explicit margin of safety to account for uncertainties inherent in the TMDL development process,
7. It must allow adequate opportunity for public participation in the TMDL development process,
8. It must provide reasonable assurance that the TMDL can be met.

The following document details the development of a bacteria TMDL for Tuckahoe Creek and its major tributaries, which were listed as impaired on Virginia's 1998 and 2002 303(d) Total Maximum Daily Load Priority Lists. There were four separate impaired segment listings in the 2002 303(d) list for the Tuckahoe Creek watershed: Tuckahoe Creek (8.7 mi.), Little Tuckahoe Creek (5.25 mi.), Major Tuckahoe Creek tributaries (Anderson, Broad, Georges and Readers Branches, 11.76 mi.), and Deep Run (4.49 mi.). Thus approximately 30.2 miles of Tuckahoe Creek and tributaries were listed as impaired due to a violation of Virginia's water quality standard for fecal coliform bacteria and dissolved oxygen (DO).

A glossary of terms used throughout this report is presented as Appendix A.

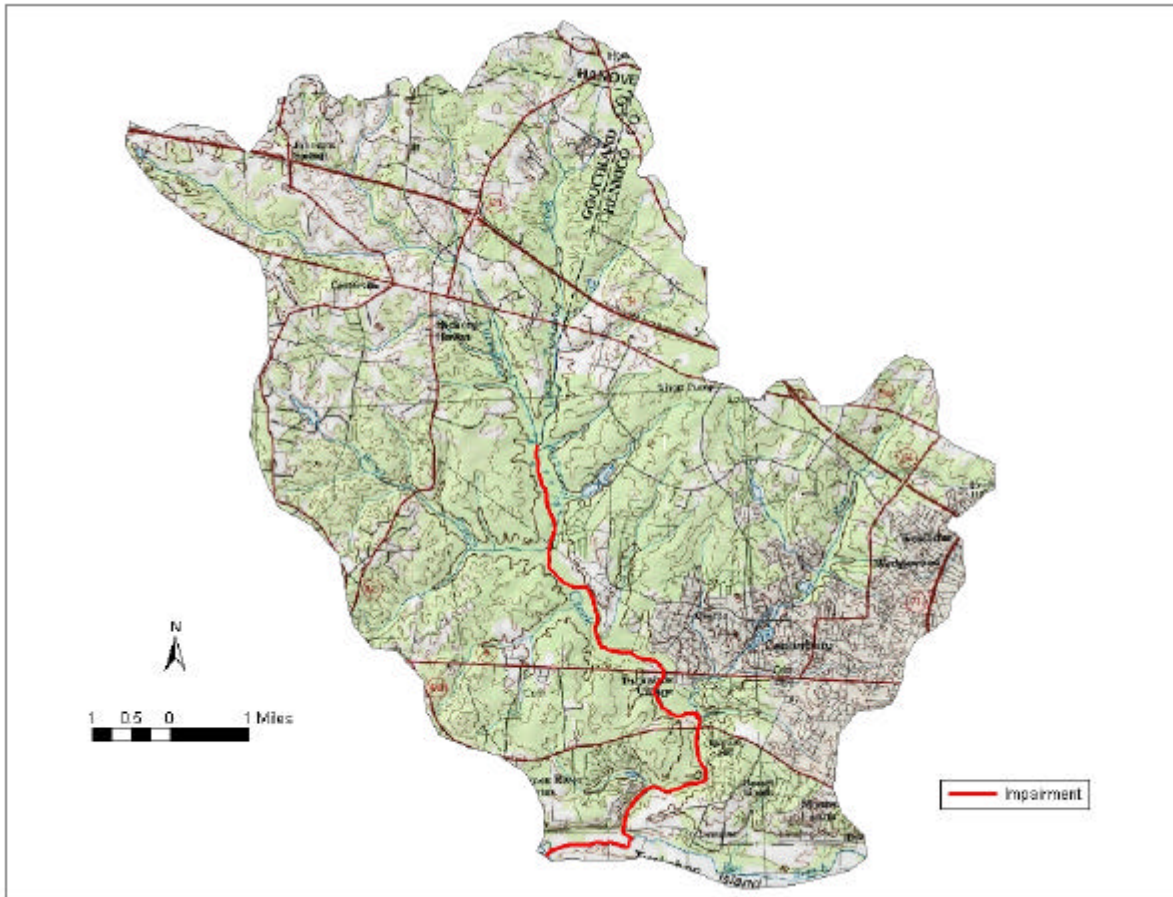
2. Physical Setting

2.1. Listed Water Bodies

This bacterial TMDL encompasses **four** 303(d) listed impaired segments in the Tuckahoe Creek watershed. The Tuckahoe Creek watershed is located in Henrico and Goochland Counties in the James River Basin (USGS Hydrologic Unit Code 02080205). The waterbody identification code (WBID, Virginia Hydrologic Unit) for Tuckahoe Creek is VAP-H39R. There are 89.51 total stream miles in the Tuckahoe Creek watershed (National Hydrography Dataset (NHD)). The four bacteria impaired segments total 30.2 miles long. They contain Tuckahoe Creek from its confluence with Little Tuckahoe Creek downstream to the James River at Tuckahoe Island, the major tributaries of Tuckahoe Creek including Little Tuckahoe Creek, Anderson, Broad, Georges and Readers Branches, but excluding mainstem Tuckahoe Creek above Little Tuckahoe Creek, and Deep Run upstream of the impoundment at rivermile 1.47 at Pump Road (Table 1 and Figure 1). Figure 1 highlights only mainstem Tuckahoe Creek below Little Tuckahoe Creek as impaired, omitting the major tributaries. A dissolved oxygen impairment in the same segments will be addressed separately from this document.

Table 1. Impaired segment description (Tuckahoe Creek)

Segment (segment ID)	Impairment (source of impairment)	Upstream Limit Description	Downstream Limit Description	Miles Affected
Major Tuckahoe Creek Tributaries: Anderson, Broad, Georges and Readers Branches (Seg ID# VAP-H39R- 01)	Fecal Coliform bacteria Dissolved Oxygen (Unknown)	Tributary headwaters; (excludes mainstem Tuckahoe Creek above Little Tuckahoe Creek)	Tributary mouths	11.76
Tuckahoe Creek (Seg ID# VAP-H39R- 02)	Fecal Coliform bacteria Dissolved Oxygen (Unknown)	Confluence with Little Tuckahoe Creek	James River at Tuckahoe Island	8.7
Little Tuckahoe Creek (Seg ID# VAP-H39R- 03)	Fecal Coliform bacteria Dissolved Oxygen (Unknown)	Headwaters	Confluence with Tuckahoe creek	5.25
Deep Run (Seg ID# VAP-H39R- 04)	Fecal Coliform bacteria Dissolved Oxygen (Unknown)	Headwaters	Pond at rivermile 1.47 at Pump Road	4.49

Figure 1. Map of the Tuckahoe Creek study area

2.2. Watershed

2.2.1. General Description

Tuckahoe Creek, located entirely within Hanover County, is a minor tributary to the James River. It is about 17 miles long and flows southeastward from its headwaters 2 miles east of Oilville to its confluence with the James River. The watershed itself is approximately 13 miles long and 5 miles wide, having an area of 64.3 square miles. The major tributaries to Tuckahoe Creek are Little Tuckahoe Creek and Anderson Branch entering from the north, Broad and Readers Branches entering from the west, and Deep Run and Georges Branch entering from the east.

2.2.2. Geology, Climate, Land Use

Geology and Soils

Tuckahoe Creek is in the Piedmont physiographic region. The Piedmont of Virginia extends eastward from the Blue Ridge to the Fall Line, where Paleozoic-age and older igneous and metamorphic rocks are covered by unconsolidated sediments of the Atlantic Coastal Plain. The Virginia Piedmont is part of the greater southeastern Piedmont, which extends from northeastern Alabama through Georgia, South Carolina, North Carolina, Virginia, Maryland, and southeastern Pennsylvania. The Piedmont is characterized by deeply weathered, poorly exposed bedrock and a high degree of geological complexity, making it one of the last frontiers of North American regional geology. (<http://www.geology.state.va.us/DOCS/Geol/pied.html>).

Soils for the Tuckahoe Creek watershed were documented utilizing the VA State Soil Geographic Database (STATSGO). Two general soil types were identified using in this database. Descriptions of these soil series were derived from queries to the USDA Natural Resources Conservation Service (NRCS) Official Soil Series Description web site (<http://ortho.ftw.nrcs.usda.gov/cgi-bin/osd/osdname.cgi>). Figure 2 shows the location of these general soil types in the watershed.

The Cecil-Madison-Enon-Wilkes-Chewacla series (VA019) are very deep to shallow soils which have been formed from residuum weathered from igneous and high-grade metamorphic rocks, or alluvium deposits of these same parent materials. Located in the Piedmont uplands, these soils are located on ridges and side slopes of the Piedmont uplands and floodplains. This series are moderately drained in the uplands and somewhat poorly drained in floodplains. Soils are moderate to slowly permeable.

Soils of the Appling-Wedowee-Ashlar-Louisburg-Vance-Worsham series (VA030) moderate to very deep that formed in residuum from weathered crystalline rock of the Piedmont Plateau. Soils range from excessively to poorly drained, with moderately rapid to slow permeability.

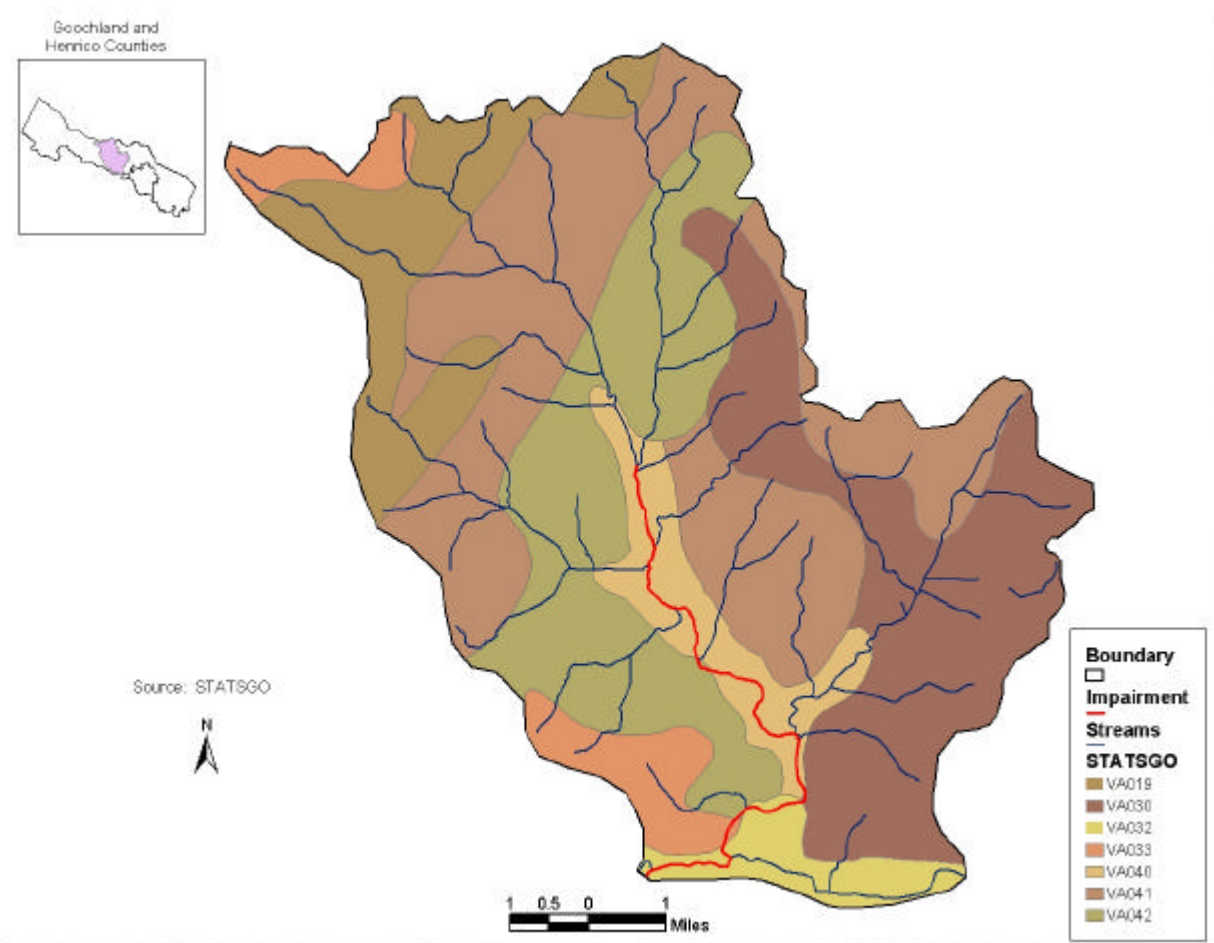
The Altavista-Congaree-Chewacla-Wehadkee-Wickham-Turbeville-Hiwassee series (VA032) are very deep to deep soils. Soils are located on stream terraces in the Piedmont and Upper Atlantic Coastal Plain. This series is formed from recent fluvial sediments. The drainage class is moderately well to very poorly drained, with moderate to poor permeability.

Soils of the State-Turbeville-Hiwassee-Dogue-Augusta-Congaree-Chewacla-Wehadkee-Edgehill series (VA033) are very deep to deep soils. Soils are located on stream terraces in the Piedmont and Upper Atlantic Coastal Plain. This series is formed from recent fluvial sediments. The drainage class is moderately well to very poorly drained, with moderate to poor permeability.

Soils of the Bojac-Pamunkey-Munden-Angie-Augusta-Molena-Argent (VA040) series are found mainly in floodplains and terraces. These soils are very deep and range from well drained to poorly or very poorly drained. Permeability for this series ranges from moderately rapid in the uplands to slowly permeable soils formed in clayey marine sediments.

Soils of the Colfax-Bourne-Helena-Vance-Orange series (VA041) consists are well drained to somewhat poorly drained. Permeability is moderate to slow. These soils formed from residuum weathered from acid and basic rocks in the Piedmont.

The Creedmoor-Partlow-Mayodan-Pinkston soils (VA042) are very deep, well drained to poorly drained soils. Permeability for this series ranges from moderately rapid to slow. These soils have formed either from Triassic material or in local colluvial and alluvial materials.

Figure 2. Soil Characteristics of the Tuckahoe Creek Watershed**Climate**

The climate summary for the Tuckahoe Creek watershed comes from a weather station located in Ashland, VA, within 13 miles of the study area, with a period of record from 8/02/1948 to 12/31/2002. The average annual maximum and minimum temperature (°F) at the weather station is 68.1 and 45.2 and the annual rainfall (inches) is 42.2 (Table 2) (Southeast Regional Climate Center, <http://cirrus.dnr.state.sc.us/cgi-bin/sercc/cliMAIN.pl?va0327>).

Table 2. Climate summary for Ashland, Virginia (440327)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	46.4	50.6	58.9	69.7	76.6	83.6	87.1	85.7	79.7	69.2	59.7	49.4	68.1
Average Min. Temperature (F)	25.4	28.2	34.3	43.5	52.8	61.1	65.7	64.5	57.6	45.4	35.8	28.4	45.2
Average Total Precipitation (in.)	3.34	3.03	3.86	3.06	3.83	3.37	4.23	4.07	3.67	3.37	3.09	3.28	42.20

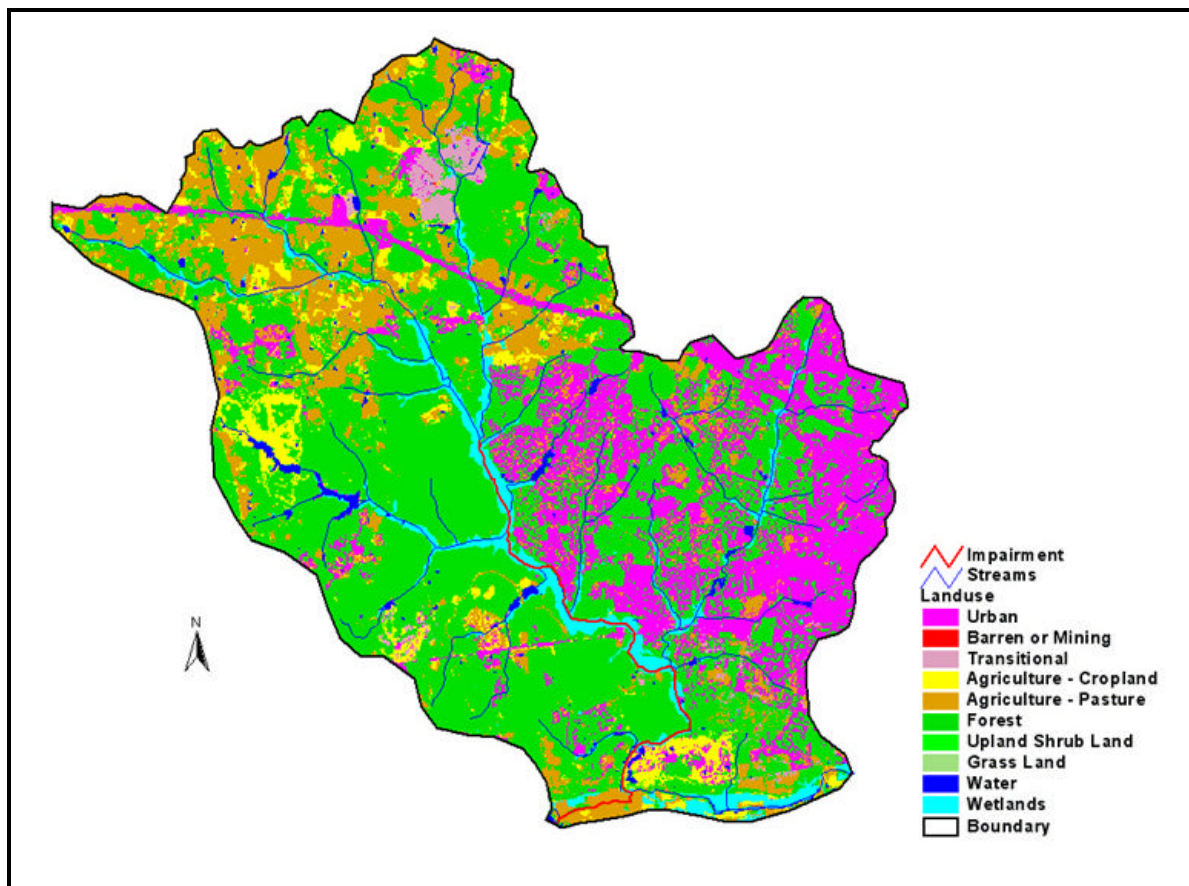
Land Use

The Tuckahoe Creek watershed extends approximately 13 miles upstream from the stream's confluence with the James River and is approximately 5 miles wide. The approximately 41,200 acre watershed is predominately forested (52.3 percent). Agriculture encompasses 22.0 percent of the watershed, with 5.4 percent cropland and 16.5 percent pasture/hayland. Residential and high use industrial areas compose approximately 19.7 percent of the land base. Transitional use composes 1.5 percent of the watershed. The remaining 4.7 percent of the watershed is comprised of wetlands and open water.

A map of the distribution of land use in the watershed (Figure 3) shows that urban land is found in the eastern portions of the watershed. Forest land is found primarily in the southern and western portions of the watershed. Agriculture is scattered in the northern part of the watershed.

Table 3. Land Use in the Tuckahoe Creek Watershed

Landuse Category	Area (acres)	Area (%)
Open Water	51.8	0.13
Low Intensity Residential	5555.0	13.50
High Intensity Residential	1.1	0.00
High Intensity Commercial/Industrial	2531.1	6.15
Quarries/Strip Mines/Gravel Pits	3.3	0.01
Transitional	611.4	1.48
Deciduous Forest	13173.8	31.99
Evergreen Forest	1946.6	4.73
Mixed Forest	6418.5	15.59
Pasture/Hay	6777.7	16.46
Row Crops	2225.5	5.40
Woody Wetlands	1203.4	2.92
Emergent Herbaceous Wetlands	677.2	1.64
Total Acres	41176.4	100.00
Total Square Miles	64.3 sq. mi.	

Figure 3. Land Use in the Tuckahoe Creek Watershed

3. Description of Water Quality Problem/Impairment

The major Tuckahoe Creek tributaries Anderson, Broad, Georges and Readers Branches (2002 303(d) Segment ID# VAP-H39R-01) were listed as threatened on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report and 2002 303(d) Report on Impaired Waters (VADEQ, 1998 & 2002) due to violations of the State's water quality standard for fecal coliform bacteria and DO at the mainstem Tuckahoe Creek station 2-TKO004.69.

Tuckahoe Creek (2002 303(d) Segment ID# VAP-H39R-02) was listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report and 2002 303(d) Report on Impaired Waters (VADEQ, 1998 & 2002) due to violations of the State's water quality standard for fecal coliform bacteria and DO. Out of 19 bacteria samples collected during the 1998 assessment period, 5 violated the water quality standard. During the subsequent 2000 assessment period, 8 of 31 samples violated the water quality standard, and during the most recent 2002 assessment period, 6 of 47 samples violated the standard. A total of 99 fecal coliform samples, with 18 water quality standard violations, have been taken by DEQ at station 2-TKO004.69 (Figure 4) from July 1990 through December 2003 (Table 4a). A total of 22 E. coli samples, with 5 water quality standard violations, have also been taken at the same station between September 2002 through December 2003. In 2003 there were three occasions where only E. coli samples were taken, and no corresponding fecal coliform samples.

Little Tuckahoe Creek (2002 303(d) Segment ID# VAP-H39R-03) was listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report and 2002 303(d) Report on Impaired

Waters (VADEQ, 1998 & 2002) due to violations of the State's water quality standard for fecal coliform bacteria and DO. During the 2000 assessment period, 3 of 13 samples violated the water quality standard. During the 2002 assessment period, 10 of 35 samples violated the standard. A total of 51 fecal coliform samples, with 17 water quality standard violations, have been taken by DEQ at station 2-LIY001.73 (Figure 4) from July 8, 1997 1990 through December 11, 2003 (Table 4b). A total of 20 E. coli samples, with 12 water quality standard violations, have also been taken at the same station from March 2000 through December 2003.

Deep Run (2002 303(d) Segment ID# VAP-H39R-04) was listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report and 2002 303(d) Report on Impaired Waters (VADEQ, 1998 & 2002) due to violations of the State's water quality standard for fecal coliform bacteria and DO. During the 2000 assessment period, 8 of 18 samples violated the water quality standard. During the 2002 assessment period, 18 of 41 samples violated the standard. A total of 57 fecal coliform samples, with 22 water quality standard violations, have been taken by DEQ at station 2-DPR002.46 (Figure 4) from July 8, 1997 through December 11, 2003 (Table 4c). A total of 21 E. coli samples, with 7 water quality standard violations, have also been taken at the same station from March 2000 through December 2003.

Finally, an upstream station on Tuckahoe Creek at Rt. 250, 2-TKO010.64, was sampled from July 1997 to April 2001. A total of 43 fecal coliform samples, with 4 water quality standard violations, have been taken by DEQ at station 2-TKO010.64 (Figure 4) from July 8, 1997 through April 18, 2001 (Table 4d). From these results at less than a 10 percent violation rate, the upper portion of mainstem Tuckahoe Creek above Little Tuckahoe Creek was removed from the 303(d) segment in the 2002 assessment.

Table 4a. Fecal coliform data collected by DEQ on Lower Tuckahoe Creek at Rt. 6

Station	Date of First Sample	Date of Last Sample	Number of Samples	(Cfu/100 ml)			Number of Exceedances*
				Average	Minimum	Maximum	
2-TKO004.69	07/18/1990	12/11/2003	99	800	10	16000	18

* Exceedances of the then-applicable instantaneous standard of 1,000 cfu/100 mL, and 400 cfu/100mL after Jan 2003

Table 4b. Fecal coliform data collected by DEQ on Little Tuckahoe Creek

Station	Date of First Sample	Date of Last Sample	Number of Samples	(Cfu/100 ml)			Number of Exceedances*
				Average	Minimum	Maximum	
2-LIY001.73	07/8/1997	12/11/2003	51	1440	20	16000	17

* Exceedances of the then-applicable instantaneous standard of 1,000 cfu/100 mL, and 400 cfu/100mL after Jan 2003

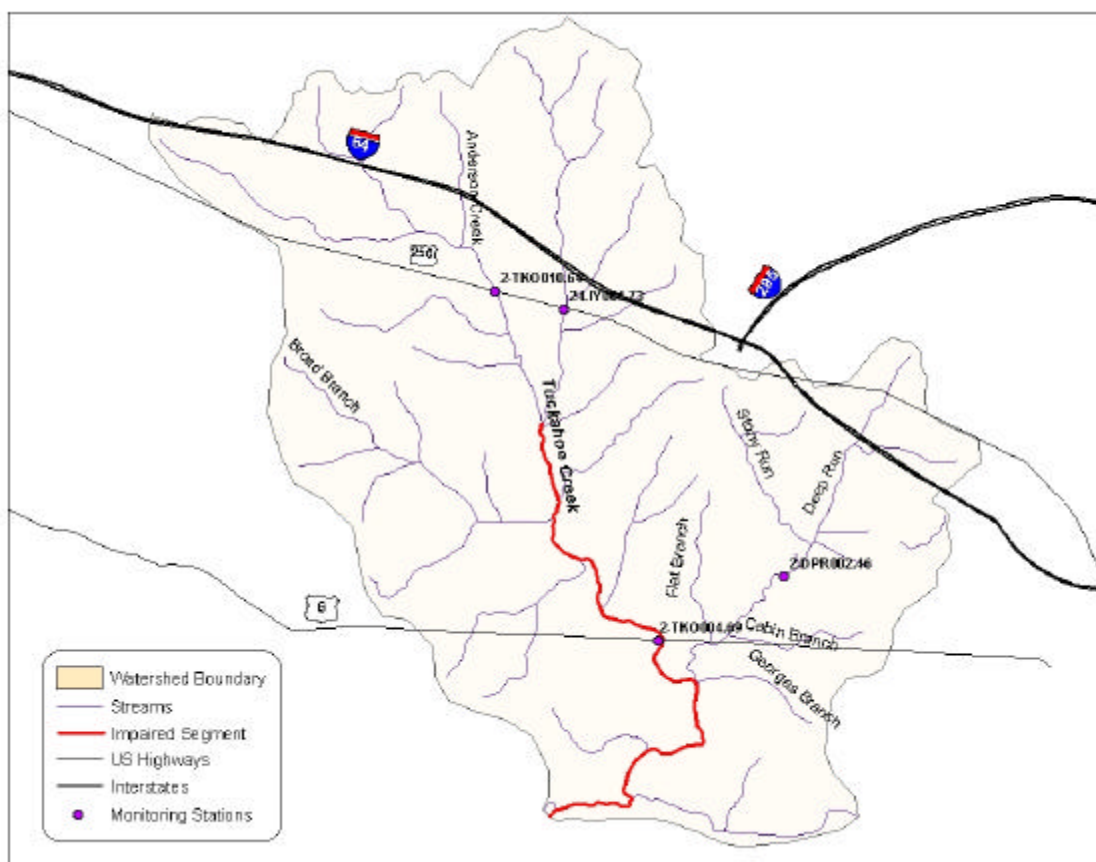
Table 4c. Fecal coliform data collected by DEQ on Deep Run

Station	Date of First Sample	Date of Last Sample	Number of Samples	(Cfu/100 ml)			Number of Exceedances*
				Average	Minimum	Maximum	
2-DPR002.46	07/8/1997	12/11/2003	57	2013	45	16000	22

* Exceedances of the then-applicable instantaneous standard of 1,000 cfu/100 mL, and 400 cfu/100mL after Jan 2003

Table 4d. Fecal coliform data collected by DEQ on Upper Tuckahoe Creek at Rt. 250

Station	Date of First Sample	Date of Last Sample	Number of Samples	(Cfu/100 ml)			Number of Exceedances*
				Average	Minimum	Maximum	
2-TKO010.64	07/8/1997	4/18/2001	43	826	18	16000	4

Figure 4. Map of Tuckahoe Creek watershed with stations 2-TKO004.69, 2-LIY001.73, 2-TKO010.64, and 2-DPR002.46

A time series graph of all data collected at station 2-TKO004.69 shows the FC concentrations ranging from 10 to 16000 cfu/100 ml (Figure 5). The horizontal line at the 1000 cfu/100 ml and 400 cfu/100ml marks represents the then-applicable instantaneous fecal coliform water quality standards. The data points above the 1000 cfu/100 ml / 400 cfu/100 ml line illustrate violations of the water quality standard.

Figure 5. Time series of fecal coliform concentrations (station 2-TKO004.69)

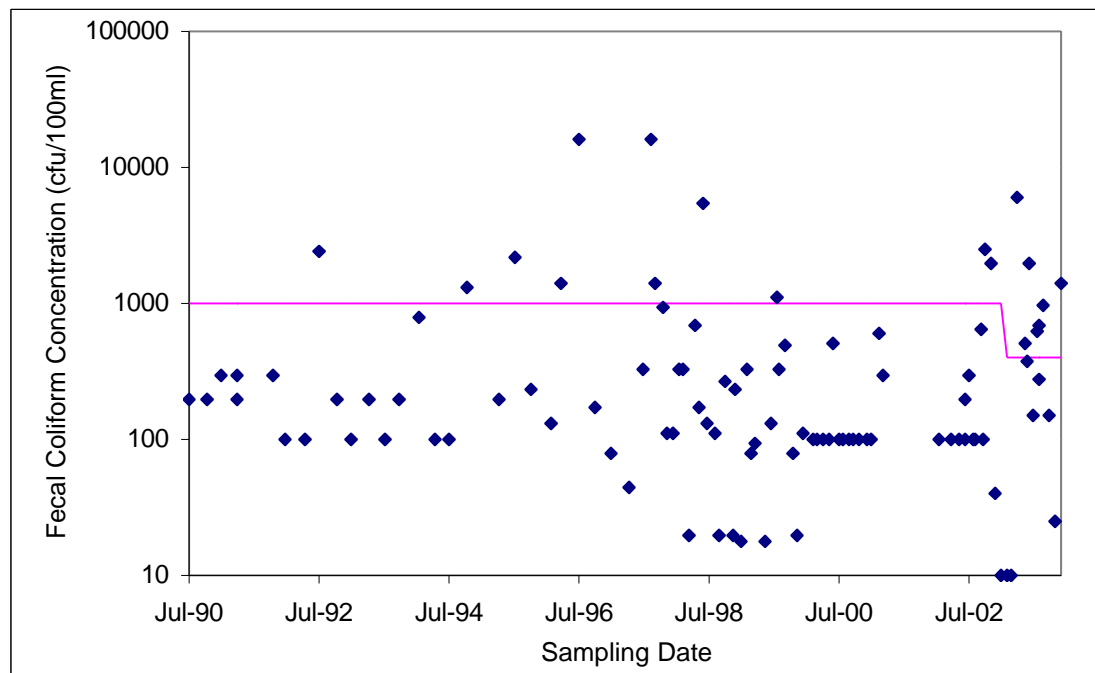
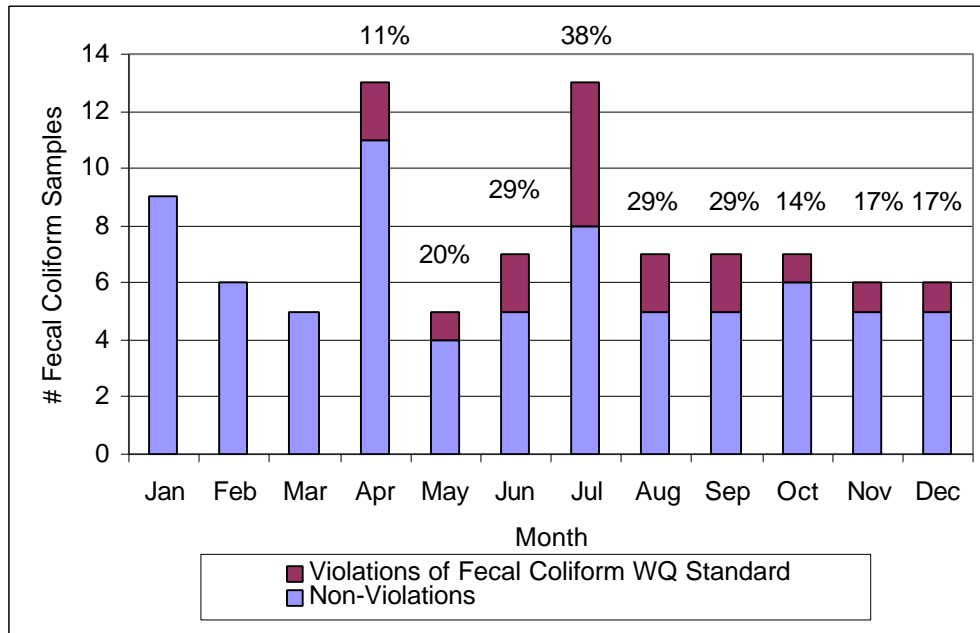


Figure 6 presents the number of water samples and exceedances (instantaneous fecal water quality standard - 1000 cfu/100mL, or 400 cfu/100mL after Jan 2003) by month.

Figure 6. Monthly distribution of fecal coliform samples and violations (station 2-TKO004.69)



4. Water Quality Standard

According to Virginia Water Quality Standards (9 VAC 25-260-5), the term “water quality standards means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.).”

As stated above, Virginia water quality standards consist of a designated use or uses and a water quality criteria. These two parts of the applicable water quality standard are presented in the sections that follow.

4.1. Designated Uses

According to Virginia Water Quality Standards (9 VAC 25-260-10A), “all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish).”

As stated above, Tuckahoe Creek must support all designated uses and meet all applicable criteria.

4.2. Applicable Water Quality Criteria

The applicable water quality criteria for bacteria in the Tuckahoe Creek watershed has changed since the initial listing on the 303(d) report. Following EPA recommendations, the Virginia Department of Environmental Quality (DEQ) proposed more stringent fecal coliform bacteria standards as well as new standards for *Escherichia coli* (*E. coli*) bacteria. These new standards were adopted by the State Water Control Board in May 2002, public noticed in June 2002, approved by the USEPA in November 2002, and were effective January 15, 2003.

The EPA recommendation that states adopt *E. coli* and enterococci (saltwater) standards stems from a stronger correlation between the concentration of *E. coli* and enterococci organisms and the incidence of gastrointestinal illness. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. *E. coli* is a subset of fecal coliform group; thus a waterbody listed as impaired for fecal coliform is considered to be listed for *E. coli* as well.

Although Tuckahoe Creek was listed as impaired due to a violation of the previous fecal coliform standard, the TMDL must be developed to meet the new *E. coli* bacteria standard. The interim fecal coliform bacteria standard presented below will not apply to this TMDL since 12 *E. coli* bacteria samples were collected as part of the bacteria source tracking study of the source assessment.

New Bacteria Standards

For a non-shellfish supporting water body to be in compliance with Virginia bacteria standards for primary contact recreational use, the DEQ specifies the following criteria (9 VAC 25-260-170):

1. *Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*

2. *E.coli and enterococci bacteria per 100 ml of water shall not exceed the following:*

Table 5. Applicable water quality standards

Parameter	Geometric Mean ¹ (cfu/100 ml)	Single Sample (cfu/100 ml)
<i>E.coli</i> (fresh water)	126	235
Enterococci (saltwater & Transition Zone 3)	35	104

¹ for two or more samples taken during a calendar month.

If the waterbody exceeds the criterion of greater than 10.5 percent water quality standard violations, the waterbody is classified as impaired and a TMDL must be developed and implemented to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion is applied to a particular datum or data set (9 VAC 25-260-170). If the sampling frequency is one sample or less per calendar month, the instantaneous criterion is applied; for a higher sampling frequency, the geometric mean criterion is applied.

For Tuckahoe Creek, the TMDL is required to meet the instantaneous criterion since the load-duration approach used to develop the TMDL for Tuckahoe Creek yields the maximum allowable bacteria concentration under any given flow condition. Unlike a continuous time series simulation, the flow duration approach does not yield daily bacteria concentrations which are needed to apply the geometric

mean standard. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect bacteria loading.

5. Assessment of Bacteria Sources

The assessment bacteria sources in traditional bacteria TMDL studies involves estimating loads from sources in the watershed and developing a computer model to establish the links between estimated loads and actual in-stream bacteria concentrations.

In a load-duration bacteria TMDL, source assessment is accomplished by determining the relative contribution by source of the fecal bacteria contained in a sample of stream water. This method of source identification is achieved through microbial source tracking (MST). MST methods that specifically use bacteria as the target organism are referred to collectively as bacteria source tracking (BST) methods. MST has been applied to study microbial ecology of environmental systems for years and are now being applied to help improve water quality by identifying problem sources and determining the effect of implemented remedial solutions. Management and remediation of water pollution would be more cost effective if the correct sources could be identified (Simpson, 2002).

To support BST analyses in load-duration TMDLs, bacteria loading in a watershed is also estimated. These load estimates are broken into point and non-point sources. It is important to note that the non-point source load estimates represent loading to the surface of the watershed; they are not estimates of in-stream loads.

The following sections present BST analysis and point- and non-point source load estimates.

5.1. Bacteria Source Tracking (BST)

Background

MST methods can be divided into three categories: molecular (genotype), biochemical (phenotype), and chemical. Molecular methods may offer the most precise identification of specific types of sources but are limited by high per-isolate costs and detailed and time-consuming procedures. They are not yet suitable for assaying large numbers of samples in a reasonable time frame. Biochemical methods (BST) may or may not be as precise, but are more simple, quicker, less costly, and allow large numbers of samples to be assayed in a short period of time (Hagedorn, 2002).

Several biochemical BST methods are in various stages of development. Among these are Antibiotic Resistance Analysis (ARA), F-Specific (F+ or FRNA) Coliphage, Sterols or Fatty Acid Analysis, Nutritional Patterns, and Fecal Bacteria Ratios. Of these, ARA has been chosen as the BST method for this TMDL report.

The ARA method uses fecal streptococcus (including the enterococci) and/or *E. coli* and patterns of antibiotic resistance for separation of sources. The premise is that human fecal bacteria will have the greatest resistance to antibiotics and that domestic and wildlife animal fecal bacteria will have significantly less resistance (but still different) to the battery of antibiotics and concentrations used. Most investigators are testing each isolate on 30 to 70+ antibiotic concentrations (Hagedorn, 2002). A more detailed description of the ARA method used by MapTech, Inc. in support of this TMDL is presented in Appendix B.

BST Sampling and Results

A total of 12 ambient water quality samples were collected by DEQ staff and submitted to MapTech, Inc. (MapTech) for BST analysis. The BST analyses performed by MapTech determined the relative contribution of overall bacteria by human, canine, livestock, and wildlife sources. Fecal and *E. coli* bacteria were also enumerated as part of the analyses performed by MapTech. Results of the Tuckahoe Creek BST sampling program are presented in Table 6.

Table 6. Tuckahoe Creek bacteria source tracking results

Sample Date	Fecal Coliform (cfu)	<i>E. coli</i> (cfu)	BST Distribution (%)			
			Human	Pet	Livestock	Wildlife
9/23/02	650	110	17	53	17	13
10/16/02	2500	780	25	8	54	13
11/12/02	2000	1200	4	42	29	25
12/9/02	40	20	0	5	68	27
1/13/03	10	BDL	-	-	-	-
2/11/03	10	BDL	-	-	-	-
3/11/03	10	BDL	-	-	-	-
4/7/03	6000	2000	37	29	13	21
5/28/03	500	87	8	17	33	42
6/17/03	2000	340	4	71	4	21
7/28/03	630	200	17	62	0	21
8/5/03	700	110	0	67	33	0
Average			12	39	28	20
Standard Deviation			13	26	22	12

The BST data results indicate that the majority bacteria are coming from anthropogenic sources. Approximately 79% of the bacteria found in the Tuckahoe Creek study comes from human, pet, or livestock sources.

5.2. Point Sources

Bacteria loading from point sources such as sewage treatment plants, small commercial establishments, schools, homes and businesses require permits under the Virginia Pollution Discharge Elimination System (VPDES) permit program. In order to consider all such point-source discharges in the Tuckahoe Creek watershed, the DEQ comprehensive environmental database, regional DEQ permit staff, and local Virginia Department of Health (VDH) offices were all queried.

There are two VPDES permittees (Henrico County Water Treatment Plant (WTP) VA0091197 and Henrico County Separate Storm Sewer System VA0088617), and two Stormwater General Permits (Henrico County Water Treatment Plant (VAR440575 and Short Pump Town Center VAR440710) in the Tuckahoe Creek watershed. None of these facilities in the Tuckahoe Creek watershed are permitted for sewage discharge. However the Henrico County WTP VA0091197 has a low chlorine limit for occasional discharged potable water. To be conservative, the Henrico County WTP VA0091197 will be used to determine a fecal bacteria load allocation for rare discharges.

Current EPA guidance requires a bacterial waste load allocation to be determined for MS4 permits. In three previous bacterial TMDLs (Accotink Creek, Four Mile Run, and Lynnhaven Bay) DEQ estimated MS4 bacterial waste load allocation by the % impervious portions of urban land use area. Note that the TMDL does not directly model MS4 bacterial wasteload allocation, but derives a gross estimate of the

MS4 wasteload allocation. Percent imperviousness for Tuckahoe Creek urban land use was determined from Table 5.5, page 37, of the Lynnhaven Bay bacterial TMDL (VADEQ, 2003). Low intensity residential land use in the Tuckahoe watershed was given 20% imperviousness from the Single family / duplex land use for Lynnhaven Bay. The high intensity residential Tuckahoe land use was given 50% imperviousness from townhouse imperviousness in Lynnhaven, and high intensity commercial Tuckahoe land use was given 70% imperviousness from commercial land use in Lynnhaven. The acres of these three urban Tuckahoe land uses were multiplied by the respective % imperviousness, and the resulting impervious acres were totaled. Then the impervious acres were divided by the total acres in the Tuckahoe watershed, to give % impervious acres in the Tuckahoe watershed. This was equated with over % imperviousness in the Tuckahoe watershed, which was multiplied by the non-point source TMDL allowable load determined below in Section 6.2. The Henrico MS4 wasteload allocation was estimated to be 1.05×10^{13} cfu/yr. The calculation is described in Appendix C.

Table 7 describes the VPDES and VAR point source facilities and loads in the Tuckahoe Creek watershed.

Table 7. VPDES, VPA, VAG and VAR point source facilities and loads

Stream Name	Facility Name	VPDES Permit Number	Discharge Type¹	Design Flow (MGD)	Permitted <i>E.coli</i> Limit (cfu/100 ml)	<i>E. coli</i> Wasteload Allocation (cfu/yr)
UT to Tuckahoe Creek	Henrico County Water Treatment Plant	VA0091197	Municipal Minor	0.70	126 cfu/100 ml (Occasional load)	1.22×10^{12}
UT to Tuckahoe Creek	Henrico County Water Treatment Plant	VAR440575	General Stormwater	NL	0	0
Little Tuckahoe and Harding Creeks	Short Pump Town Center	VAR440710	General Stormwater	NL	0	0
					Total	1.22×10^{12}
Existing WLA						
Expansion Matrix						
					Total X 2	2.44×10^{12}
					Total X 5	6.10×10^{12}
MS4 Permits						
Entire Tuckahoe Creek Watershed Urban land use	Henrico County Separate Storm Sewer System	VA0088617	MS4	NL	NA	1.05×10^{13}
					Total of TMDL WLA (non-expanded)	1.17×10^{13}

¹STP = Sewage Treatment Plant, WTP = Water Treatment Plant, SFH = Single Family Home (≤ 1000 gpd), NL = No limit, NA = Not applicable.

Where permit limits for *E. coli* exist, permitted loads were calculated by multiplying the permitted discharge concentration (126 cfu/100 ml) times the design flow times the appropriate unit conversions (1.3816345×10^{10}). The calculation is presented in Appendix C. Because Henrico County Water Treatment Plant VA0091197 has a low chlorine limit for occasional discharged potable water, it was used to determine a fecal bacteria load allocation for occasional discharges of 1.22×10^{12} cfu/yr. The Henrico MS4 wasteload allocation was determined to be 1.05×10^{13} cfu/yr as described above. Future expansions of WLA X 2 and X 5 are listed above, but are not used in the TMDL calculation. A future growth factor of 5 multiplier is not used with MS4 loads because they are a non-point source contribution

and not as easily controlled. These two WLAs were totaled for the total point source wasteload allocation of 1.17×10^{13} cfu/yr.

5.3. Non-Point Sources

In order to gain an understanding of non-point source loading in the Tuckahoe Creek watershed, bacteria loads for typical non-point sources were estimated. These estimates were based upon animal and human population data sets, typical waste production rates and typical bacteria densities in waste products.

Currently published values for fecal bacteria production rates are primarily in terms of fecal coliform. There is little data on *E. coli* production; however, studies have shown that though minor variability will exist between sources, *E. coli* represents roughly 90-95% of fecal coliforms contained in "as-excreted" fecal material (Yagow, 2003). This implies that the relative bacteria contribution by source should remain constant.

It is important to note that the bacteria loads presented in the following sections on non-point sources represent "as-produced" loads. This is to say that some portion of an estimated load may not be available to be transported to Tuckahoe Creek in runoff.

5.3.1. Humans and Dogs

Bacteria loading from human sources can come from straight pipes, failing septic systems, and land-applied biosolids. Failing septic systems are typically manifested by effluent discharging to the ground surface where the bacteria laden effluent is then available to be washed into a stream as runoff during a precipitation event. In contrast, discharges from straight pipes are typically directly deposited to streams.

All biosolids can contain a certain concentration of fecal bacteria. When biosolids are applied to the land surface, the potential exists for a portion of these fecal bacteria to be transported to a stream as runoff during storm events.

Straight Pipes

The Henrico County office of the VDH reported no known straight pipes in the Tuckahoe Creek Watershed.

Septic Systems

The Tuckahoe Creek watershed totals 64.3 sq. mi., with 54.6 percent, or 35.1 sq. mi., in Goochland County; 43.4 percent, or 27.9 sq. mi., in Henrico County; and with 2.1 percent, or 1.35 sq. mi., in Hanover County. Based on 2000 U.S. Census data, the Goochland County portion of the Tuckahoe Creek watershed is populated by an estimated 2091 residents living in approximately 764 households; the Henrico County portion of the Tuckahoe Creek watershed is populated by an estimated 30,689 residents living in approximately 12,650 households; and the Hanover County portion of the Tuckahoe Creek watershed is populated by an estimated 250 residents living in approximately 94 households. The total population of the Tuckahoe Creek watershed thus is estimated at 33,030 residents in 13,508 households. This was calculated by an area ratio between the Tuckahoe Creek watershed (64.3 sq. mi.) and the Goochland, Henrico and Hanover Counties areas.

Within the Tuckahoe Creek watershed, an estimated 90 percent of Goochland households, 100 percent of Hanover households, and 5 percent of Henrico County households are serviced by private septic systems. These percentages were determined by best professional judgment. Thus approximately 1882 residents in 688 Goochland County households, 250 residents in 94 Hanover County households, and 1535 residents in 633 Henrico County Households, for a total of 3667 residents in 1415 households using septic systems in the Tuckahoe Creek watershed. Assuming a wastewater production rate of 75 gallons

per day per person (Geldreich, 1978), and a fecal coliform density in septic tank waste of 1.04×10^6 cfu per 100 mL (MapTech, 2002), the total septic load possible in the Tuckahoe Creek watershed is estimated to be 3.97×10^{15} cfu per year (Table 8a). Of this total septic load, only the load from failing septic systems would be available as runoff.

Table 8a. Estimated fecal coliform production from humans in the Tuckahoe Creek watershed

Source	Population	Waste Production Rate (/100ml/yr/person)	Waste Fecal Coliform Density (cfu/100 ml)	Total Est. Annual Fecal Production (cfu/yr)
Septic Systems	3667	75 gal/day/person x 37.85412/ 100mL/gal x 365 days/yr = 1.04×10^6 *	1.04×10^6 **	3.97×10^{15}

* Geldreich, 1978. A conversion factor of 37.85412 was used to convert gallons to 100mL.

** MapTech, 2002 (Gills Creek TMDL Report).

Septic system failure rates depend largely on the age of the septic system. Surveys of failing septic systems in other Virginia watersheds have yielded a formula for calculating a rate of septic system failures for a given area. In the preparation of a TMDL report for the Goose Creek watershed in Loudoun County, VA, such a formula was used to estimate a septic system failure rate in Loudoun County. The estimated failure rate was calculated to be as high as 17% for some portions of the county (ICPRB, 2002). In the absence of a septic system survey, the Goose Creek TMDL report specified a failure rate of 5% (ICPRB, 2002). This figure is based on the calculated failure rate, the professional judgement of the local health department, and results of a BST study completed for the Goose Creek watershed.

Other researchers estimate septic system failure rates by age of the house, as determined by presence on pre-1964, 1964 – 1984, and post-1984 topographic maps. Professional judgment was applied in assuming that septic system failure rates for houses by the pre-1964, 1964-1984, and post-1984 age categories were 40, 20, and 5%, respectively (R.B. Reneau, personal communication, 7 January 2000, Blacksburg, Va.). Estimates of these failure rates were also supported by the Holmans Creek Watershed Study (a watershed located just north of Linville Creek), which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001)."

For this TMDL we assumed a 10% failure rate, taking into account that many of the homes are pre – 1984 construction, and the lower ICPRB estimates based on literature and local health department best professional judgment. At the 10% failure rate, with an estimated annual production rate of 3.97×10^{15} cfu/yr, the annual septic loading available as runoff to Tuckahoe Creek was estimated to be 3.97×10^{14} cfu/yr.

Biosolids

In the Commonwealth of Virginia, the VDH and the DEQ regulate biosolids generation and application to the land surface. The DEQ regulates the generation of biosolids and the land application of those biosolids by the generator. The VDH regulates contractors who transport and spread biosolids; the biosolids can be from in-state or out-of-state sources.

The DEQ comprehensive environmental database was queried for biosolids application permits in the Tuckahoe Creek watershed, and none were found. Likewise all biosolids use permits on file with the VDH central office were reviewed. No permits to apply biosolids in the Tuckahoe Creek watershed were found.

Dogs

The number of pets in the watershed was estimated based on the number of households. Assuming an average of 1.7 dogs and 2.1 cats per household (National Pet Owner Survey, American Pet Products

Manufacturers Association, 2001-2002), the estimated pet population in the Tuckahoe Creek watershed consists of 22,964 dogs and 28,367 cats. Cats are estimated to have approximately one millionth of the fecal coliform density of dogs, and thus are deemed insignificant in pet fecal bacteria production. Using the waste production rates and fecal coliform densities from MapTech, 2002, the total bacteria loads from dogs and cats in the Tuckahoe Creek watershed are 1.81×10^{15} cfu/yr and 1.80×10^9 cfu/yr, respectively. Table 8b presents the calculation of pet loads in the watershed. It should be noted that the numbers presented in Table 8b represent loads available for runoff and not in-stream loads.

Table 8b. Estimated fecal coliform production from pets in the Tuckahoe Creek watershed

Source	Population	Waste Production Rate/Yr	Waste Fecal Coliform Density	Total Est. Annual Fecal Production
Dogs	22,964 dogs	450 g/dog **	4.8×10^5 cfu/g **	1.81×10^{15} cfu/yr
Cats	28,367 cats	19.4 g/cat **	9 cfu/g **	1.80×10^9 cfu/yr

* Geldreich, 1978. A conversion factor of 37.85412 was used to convert gallons to 100mL.

** MapTech, 2002 (Gills Creek TMDL Report).

5.3.2. Livestock

Fecal matter from livestock can be deposited directly to the stream in instances where livestock have stream access, or the fecal matter can be transported to the stream in surface runoff from grazing or pasture lands.

The predominant types of livestock in the Tuckahoe Creek watershed are cattle and horses, although all types of livestock were considered in developing the TMDL. 1997 Census of Agriculture data for Henrico County were used to estimate the livestock population in the watershed. Hog population was withheld from the 1997 agricultural census for Henrico County, so the estimate for hogs excludes Henrico County. The Tuckahoe Creek watershed is comprised of 12.4 percent of Goochland County, 11.7 percent of Henrico County, and 0.29 percent of Hanover County, and contains approximately 6.5% of the total pastureland in the three counties as determined by area ratio of 64.3 sq. mi. in the Tuckahoe watershed / 995 sq. mi total in the three counties. Table 9 presents the livestock population estimates, ranges of fecal production rates, and ranges of estimated annual fecal production in the watershed. It should be noted that the numbers presented below represent loads available for runoff and not in-stream loads.

Table 9. Estimated annual fecal coliform production from livestock in the Tuckahoe Creek watershed

Source	Population ¹	Range of Fecal Coliform Production Rates ² (cfu/animal/day)		Range of Annual Fecal Coliform Production (cfu/yr)	
		Low	High	Low	High
Beef Cows	702	4.28×10^6	1.2×10^{12}	1.10×10^{12}	3.07×10^{17}
Dairy Cows	81	2.19×10^6	1.76×10^{12}	6.47×10^{10}	5.20×10^{16}
Pigs	57	5.01×10^6	1.72×10^{13}	1.04×10^{11}	3.58×10^{17}
Sheep	46	1.76×10^7	4.93×10^{11}	2.96×10^{11}	8.28×10^{15}
Horses ³	120	7.44×10^5	1.68×10^9	3.26×10^{10}	7.36×10^{13}
			Total Production	4.82×10^{12}	7.25×10^{17}

¹ The beef cow, dairy cow, sheep and horse populations in the Tuckahoe Creek watershed were estimated using a 6.5% ratio of Tuckahoe Creek drainage area to entire Goochland, Hanover, and Henrico County.

²VADCR, 2003

5.3.3. Wildlife

Like livestock, fecal matter from wildlife can be either deposited directly to the stream, or it can be transported to the stream in surface runoff from woods, pastureland and cropland. Direct deposition to streams varies with species, e.g. beaver spend most of their time in water; therefore most of their fecal matter would be directly deposited to the stream.

Wildlife populations in the Tuckahoe Creek watershed were estimated based on wildlife densities used in developing other bacterial TMDLs in Virginia. Deer densities were supplied by a UVA deer population model for Henrico County. Turkey, muskrat, beaver, and duck densities were supplied by Maptech 2002. Raccoon densities were taken from Yagow 1999. Geese densities used were the highest found in final and draft TMDLs in Virginia, and came from the Catoctin Creek TMDL from Loudoun County, because Henrico County is closer to the eastern flyway than Loudoun County, and appears to have a large resident geese population. See Table 10 for estimated fecal coliform production from wildlife in the Tuckahoe Creek watershed. Habitat was assigned as follows:

- deer: all land use categories
- turkey: deciduous forest, evergreen forest, mixed forest
- muskrat: woody wetlands, emergent herbaceous wetlands, open water
- beaver: stream miles
- raccoon: low intensity residential, deciduous forest, evergreen forest, mixed forest, woody wetlands, row crops
- geese: pasture/hay, row crops, emergent herbaceous wetlands, open water

Table 10. Estimated fecal coliform production from wildlife in the Tuckahoe Creek watershed

Source	Population Density	Habitat	Watershed Population (animals)	Range of Daily Fecal Coliform Production ¹ (cfu/an/day)		Range of Annual Fecal Coliform Production (cfu/yr)	
				<i>low</i>	<i>high</i>	<i>low</i>	<i>high</i>
Deer	0.020 an/ac	41176.4 ac	824	1.52×10^8	3.60×10^8	4.57×10^{13}	1.08×10^{14}
Turkey	0.01 an/ac	21538.9 ac	216	9.3×10^7		7.33×10^{12}	
Muskrat	2.75 an/ac	1932.4 ac	5315	2.50×10^7	1.90×10^8	4.95×10^{13}	3.69×10^{14}
Beaver	4.800 an/mi	89.51	430	3.00×10^5		4.71×10^{10}	
Raccoon	0.070 an/ac	30522.8 ac	2137	2.05×10^7	9.45×10^8	1.60×10^{13}	7.37×10^{14}
Geese	0.020 an/ac	9732.2 ac	195	5.87×10^4	2.25×10^9	4.18×10^9	1.60×10^{14}
Total						1.19×10^{14}	1.27×10^{15}

¹VADCR, 2003

6. TMDL Development

One of the major obstacles to improving stream water quality is that the potential sources of bacteria are numerous and the dominant sources and/or pathways are generally unknown. This can make it difficult to direct effective cleanup efforts.

Typical pathogen TMDLs are completed by developing watershed-based computer simulations that establish links between sources and in-stream water quality. While effective, the effort required to develop modeled TMDLs can be costly. In an effort to complete pathogen TMDLs in a timely and cost-effective manner, the use of load-duration analyses has been investigated. It has been determined that the load-duration method of calculating a TMDL produces a result only slightly more conservative than if the TMDL had been determined through computer modeling.

The load duration method essentially uses an entire stream flow record to provide insight into the flow conditions under which exceedances of the water quality standard occur. Exceedances that occur under low flow conditions are generally attributed to loads delivered directly to the stream such as straight pipes and livestock with access to the stream. Exceedances that occur under high flow conditions are typically attributed to loads that are delivered to the stream in stormwater runoff. Exceedances occurring during normal flows can be attributed to a combination of runoff and direct deposits.

The following sections detail the development of the load-duration TMDL and associated allocations.

6.1. Load-Duration Curve

Development of a load-duration curve begins with a flow-duration curve, and in order to develop a meaningful flow-duration curve one must have several years of flow data for the target stream or river. Where very little flow data exists for a target stream, a reference stream with the requisite flow measurements must be used similar to the paired watershed approach used in watershed-based modeling. Such is the case for Tuckahoe Creek.

The following sections detail the flow data for Tuckahoe Creek, the selection of a reference stream, development of a flow-duration curve for Tuckahoe Creek, and the creation of a load-duration curve for Tuckahoe Creek.

6.1.1. Flow Data

Tuckahoe Creek is located in eastern Henrico County and has a drainage area of 64.3 square miles. It is a tributary to the James River with its confluence at Tuckahoe Island. There is no long-term continuous flow gaging station on Tuckahoe Creek, therefore a reference gaging station must be selected.

6.1.2. Reference Stream

In order to develop a flow-duration curve for Tuckahoe Creek, it was necessary to select a reference stream with a gage having a period of record of no less than ten years.

In selecting a reference gage several factors must be considered. Among these are proximity, watershed topography, watershed size and geology. The period of record for the reference gage must also include dates that coincide with flow measurements made at the target stream - in this case Tuckahoe Creek. The ultimate goal is to find a gaged stream that behaves like the target stream.

For the Tuckahoe Creek analysis, Little River near Doswell, VA (#01671100), Fine Creek at Fine Creek Mills, VA (#02035600), Hardware River below Briery Run near Scottsville, VA (#02030000), and Deep Creek near Mannboro, VA (#02041000) were considered as possible reference gages. Fine Creek had the strongest correlation with an R value of 0.9219, and was also the closest gaging station, located approximately 10 miles west of the Tuckahoe Creek watershed. However using Fine Creek greatly over-estimated high flows in Tuckahoe Creek by two orders of magnitude. We chose Deep Creek near Mannboro, with a period of record from 1946 to 2003, for the reference gage with an R = 0.9205. The Deep Creek basin is located about 25 miles WSW of Tuckahoe Creek and the drainage area for the Deep Creek gage was 158 sq. mi. to Tuckahoe's 64.3 sq.mi. Deep Creek is admittedly a larger basin, but the other possible reference gages yielded inordinately high flows and/or inordinately low flows. Using Deep Creek, the Tuckahoe average flow was 71.34 cfs at 20.5% flow duration interval, the highest flow duration interval (i. e., lowest average flow) of all the possible reference gages. Using Deep Creek, the high flows at Tuckahoe Creek were typically $\pm 75\%$ of those at Deep Creek, which was close to what one would expect. Details of the correlation analysis and reference stream selection are presented in Appendix D.

One high flow discharge measurement (119 cfs) made on Tuckahoe Creek on October 16, 2002 near the peak of a storm runoff event was omitted from the reference stream correlation, with concurrence from the DEQ streamgaging office. With the high flow measurement included in the correlation, the R factor ranged from 0.14 to 0.58 at the possible reference gages, compared to 0.88 to 0.92 without the measurement. Preliminary gage height and flow records for the Fine Creek gage 10 miles to the west on that date showed that a peak runoff event was occurring during the time of the Tuckahoe Creek measurement. Precipitation and runoff from this storm in the Tuckahoe basin must have been much more intense for the Tuckahoe peak to have been 119 cfs and the Fine Creek peak only 16 cfs even though the peak times appeared concurrent.

6.1.3. Flow-Duration Curves

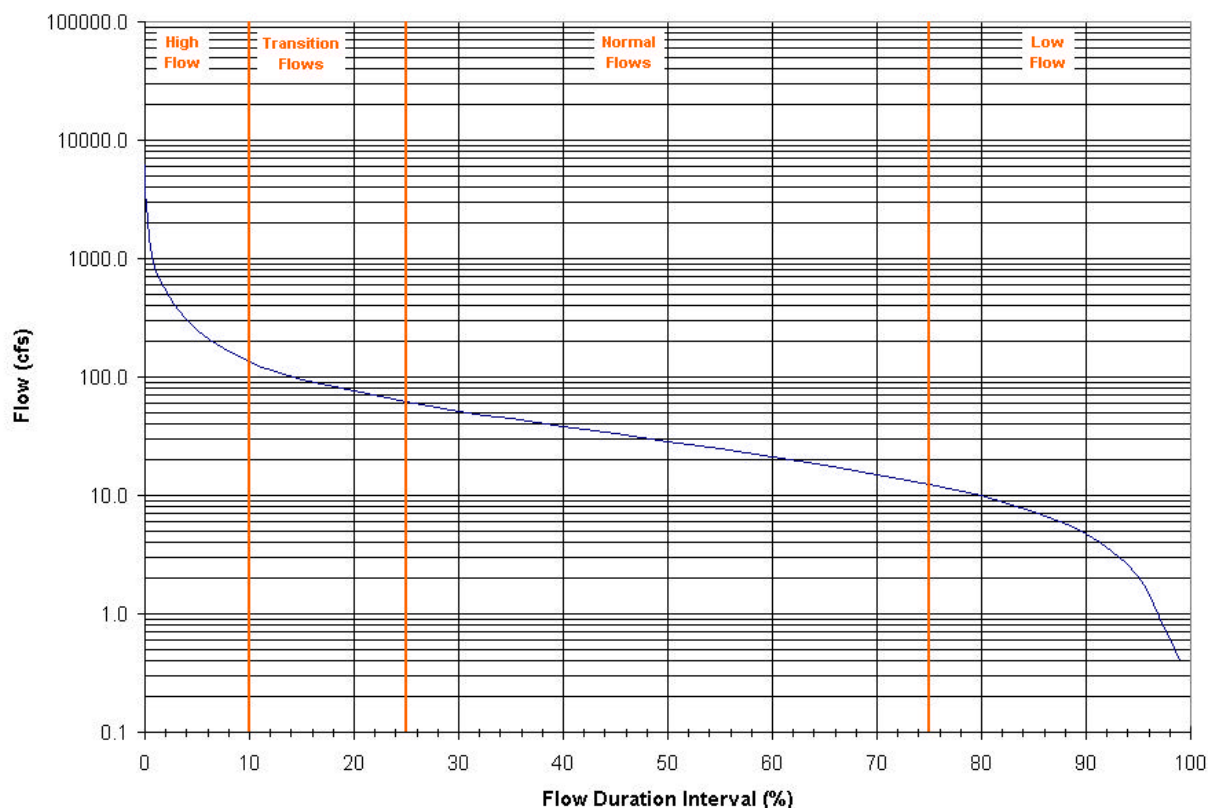
In order to use the load-duration method to develop a TMDL, a flow-duration curve must be developed for the impaired stream. This is accomplished by first developing a flow-duration curve for the reference Totopotomoy Creek gage. Then to generate a flow-duration curve for Tuckahoe Creek the Totopotomoy Creek flows corresponding to the percentiles 1%, 5%, 10%...90%, 95%, 99% were plugged into the regression equation ($y=0.2204x^{1.1343}$) obtained from the flow regression for Tuckahoe Creek with Deep Creek, and a set of flows was generated for Tuckahoe Creek. The generated flows were plotted against the percentiles from above, and a flow duration curve was drawn for Tuckahoe Creek (Figure 7).

A flow-duration curve is a plot showing the flow magnitude (cfs) along the "y" axis and the frequency of daily average stream flow (%) along the "x" axis. For example, the flow value corresponding to "1%" is the flow that has been exceeded only 1% of the time for which measurements exist. Likewise, the flow value corresponding to "30%" is the flow that 30% of the historic record exceeds.

To plot the flow values for the period of record of the reference stream, the PERCENTILE statistic function of Excel was used. The resulting percentile of a given flow was then subtracted from 1 to yield the percent of time that a given flow is exceeded by the flows of record. The flow duration interval values were plotted with the corresponding flows to yield a log/normal flow duration curve.

The flow-duration curve for Tuckahoe Creek has been divided into four sections to help illustrate flow conditions. These sections are titled "High Flows", "Transition Flows", "Normal Flows", and "Low Flows". Low flows can be roughly equated to near-drought or drought flows. High flows are near-flood or flood flows. Transition flows are, as implied, neither normal nor high.

Figure 7. Flow-duration curve for Tuckahoe Creek at Tuckahoe Village, VA (station 2-TKO004.69)



6.1.4. Load-Duration Curve

As mentioned in Section 3, all of the instream water quality BST observations on Tuckahoe Creek were collected at Station 2-TKO004.69, therefore this station is the focus of the load-duration analysis on Tuckahoe Creek.

A load-duration curve is developed by multiplying each flow level along the flow-duration curve by the applicable water quality standard and required unit conversions. The resulting curve represents the maximum allowable load at each flow level, in other words, the Total Maximum Daily Load (TMDL). Each water quality observation is then assigned to a flow interval by comparing the date of each water quality observation to the flow record of the reference stream. The reference stream flow from the date of the water quality observation is then used to calculate a stream flow and flow-duration interval for the target stream. Since the TMDL and required reductions must be in terms of an average annual stream flow, the loads on the load-duration curve are multiplied by 365 days/year and presented as annual loads.

In order to plot existing fecal coliform (FC) data against the *E. coli* (EC) standard/TMDL line, it was necessary to translate the FC data to EC data. Translation of FC data to EC data was achieved by using a translator equation developed from a regression analysis of 493 paired FC/EC data sets from the DEQ's statewide monitoring network. The translator equation resulting from the regression analysis is presented below:

$$\text{EC log}_2 = -0.0172 + 0.91905 * \text{FC log}_2$$

By plotting these observed loads on the load-duration curve, the number and pattern of exceedances of the water quality standard (TMDL) can be analyzed. **For 2002 and 2003 where possible actual *E. coli***

sample results were used to calculate observed data *E. coli* loads. The load duration curve and observed data for Tuckahoe Creek are shown in Figure 8. The TMDL line has been plotted for the instantaneous *E. coli* standard of 235 cfu/100mL.

Figure 8. Load duration curve and observed data for Tuckahoe Creek at station 2-TKO004.69

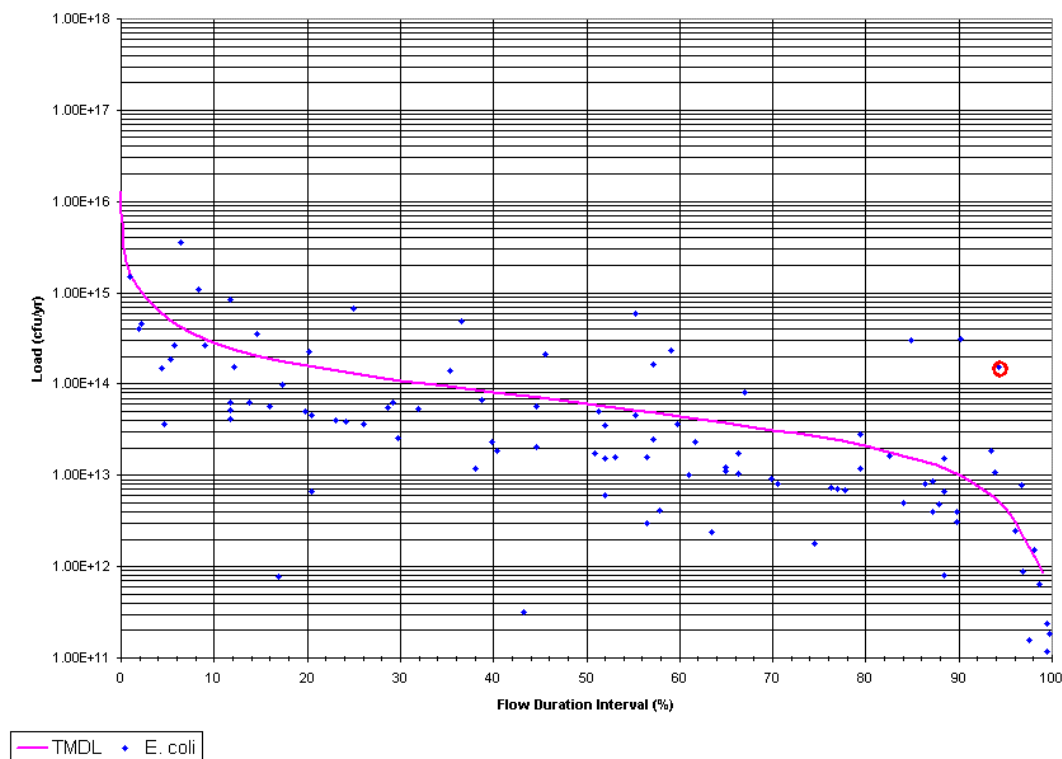
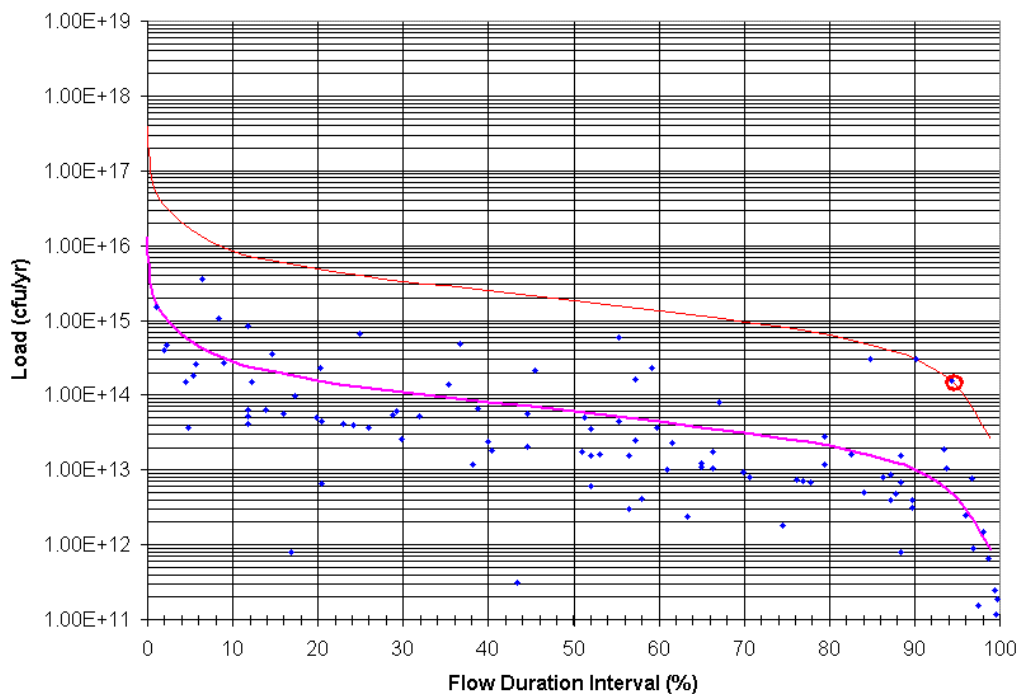


Figure 8 suggests that exceedances of the water quality standard occur under all flow conditions. The highest exceedance of the water quality standard occurred at low flows (circled in Figure 8 at 94% flow interval and 2.40 cfs). This represents the flow condition under which the largest bacteria reduction is required in order to meet water quality standards. The translated load at this flow was 1.55×10^{14} cfu/yr. Under the instantaneous *E. coli* standard of 235 cfu/100mL, these loads would have to be reduced by 97% to an allowable load of 5.03×10^{12} cfu/yr. The allowable load is simply the *E. coli* standard multiplied by the applicable flow condition and the proper unit conversions. The full calculation with unit conversions is presented in Appendix C.

In order to determine the necessary load reduction at the average annual flow condition, a second curve must be drawn through the highest exceedance described above. The second curve represents the magnitude of the highest observed exceedance if it were to occur over any flow condition. The graph of the load-duration curve with the max-exceedance curve is presented in Figure 9.

Figure 9. Load duration curve with max exceedance curve for Tuckahoe Creek at station 2-TKO004.69

6.2. TMDL

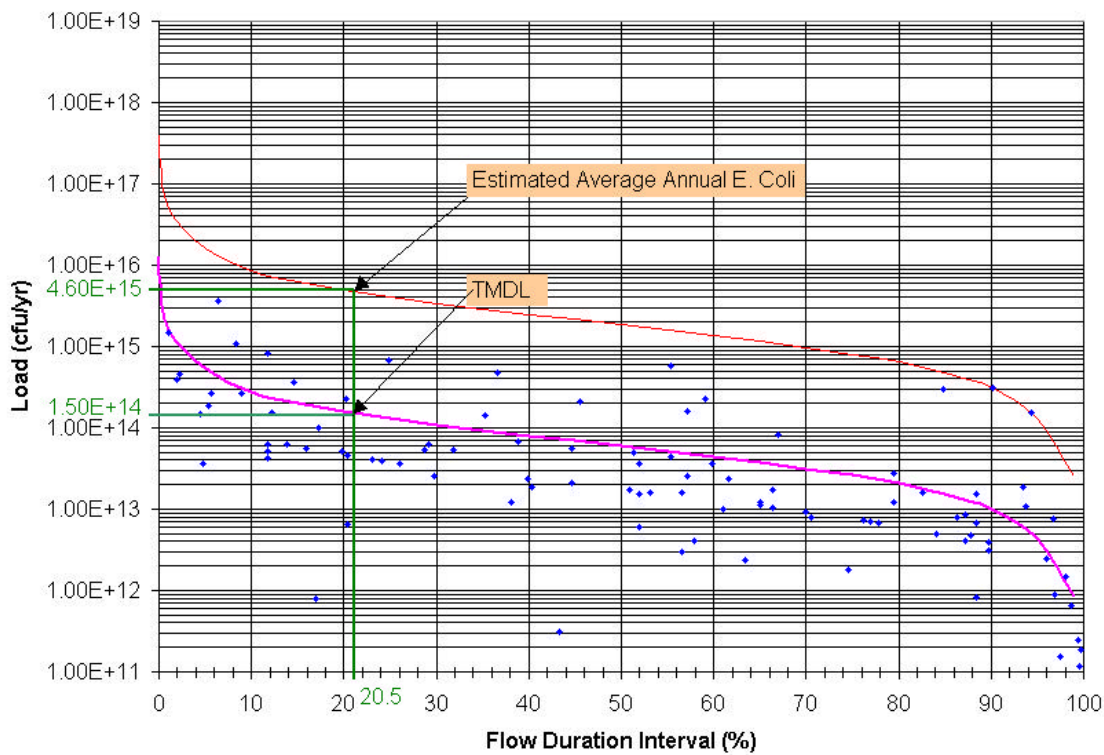
A Total Maximum Daily Load (TMDL) consists of 1) point source/waste load allocations (WLAs), 2) non-point sources/load allocations (LAs) where the non-point sources include natural/background levels, and 3) a margin of safety (MOS) where the margin of safety may be implicitly or explicitly defined. This TMDL definition is typically illustrated by the following equation:

$$\text{TMDL} = \text{WLAs} + \text{LAs} + \text{MOS}$$

Simply put, a TMDL is the amount of a pollutant that can be present in a waterbody where the waterbody will still meet water quality standards for that pollutant. In the case of load-duration bacteria TMDLs, the TMDL is expressed as the total number of colony forming units (cfu) per year as opposed to cfu/day. This is because the load-duration TMDL must be based on the average annual flow condition.

The average annual flow for Tuckahoe Creek is calculated from the regression equation $y = 0.2204X^{1.1343}$ and the average annual flow from the reference gage. The estimated average annual flow for Tuckahoe Creek is 71.34 cfs. This flow value has an associated flow duration of 20.5%. From this information an average annual *E. coli* load and TMDL can be calculated from the max-exceedance and TMDL curves. This is represented graphically in Figure 10. The full calculation is presented in Appendix C.

Figure 10. Load duration curve illustrating the TMDL and estimated average annual *E. Coli* load for Tuckahoe Creek at station 2-TKO004.69



The average annual *E. coli* load is 4.60×10^{15} cfu/yr, and the TMDL under average annual flow conditions is 1.50×10^{14} cfu/yr. These values are used to calculate required reductions. There were two dischargers given wasteload allocations. Henrico County Water Treatment Plant VA0091197 has a low chlorine limit for occasional discharged potable water, was used to determine a fecal bacteria load allocation for occasional discharges of 1.22×10^{12} cfu/yr. The Henrico MS4 wasteload allocation was determined to be 1.05×10^{13} cfu/yr as described above. These two WLAs were totaled for the total point source wasteload allocation of 1.17×10^{13} cfu/yr. Therefore, the load allocation would be determined by subtracting the waste load allocation (1.17×10^{13} cfu/yr) from the TMDL load (1.50×10^{14} cfu/yr), yielding a LA of 1.38×10^{14} cfu/yr. This is presented in Table 11.

Table 11. Average annual *E. coli* loads and TMDL for Tuckahoe Creek watershed (cfu/yr)

WLA ¹	LA	MOS	TMDL
1.17×10^{13}	1.38×10^{14}	(implicit)	1.50×10^{14}

¹ The point sources permitted to discharge in the Tuckahoe Creek watershed are presented in section 5.2.

7. Allocations

Reduction

The annual average TMDL and *E. coli* load values from section 6.2 were plugged into Table 12 to determine the required reduction. The load allocation for any future Capital Regional Airport Commission discharge proved to have an insignificant reduction of the TMDL allowable load, so that the load allocation for non-point sources virtually equaled the annual average TMDL load. The full calculations are presented in Appendix C.

Table 12. TMDL and required reduction for Tuckahoe Creek

Allowable Loads (cfu/yr)		Average Annual EC Load (cfu/yr)	Required Reduction
TMDL annual average	1.50×10^{14}		
Wasteload Allocation (WLA)	1.17×10^{13}		
MOS	(implicit)		
Load Allocation	1.38×10^{14}	4.60×10^{15}	97.00%

As illustrated in Tables 11 and 12, the WLA for the Tuckahoe Creek watershed represents approximately 7.8 percent of the TMDL annual average. An additional scenario where the point source portion of the WLA has been increased by a factor of five was developed and is presented in Appendix F. This scenario gives flexibility to accommodate future expansion and/or additional discharges in the watershed.

Margin of Safety

This requirement is intended to add a level of safety to account for any inherent uncertainty in the TMDL development process and the data used in the development. The MOS may be either implicit or explicit. An implicit margin of safety relies on the conservative nature of the assumptions, values, and methods used to calculate a TMDL whereas an explicit margin of safety is a value (typically a percentage) applied at some point during the TMDL calculation.

In the Tuckahoe Creek TMDL, an implicit MOS was incorporated through the use of conservative analytical assumptions. These include: (1) the use of the single-most extreme water quality violation event which was used to develop maximum exceedance curve over the entire range of flow conditions, and (2) the computation of average annual load using the average flow conditions. Additionally, the load duration method of TMDL development has been evaluated against TMDLs that were developed using computer modeling. The results showed the load duration method to be slightly more conservative.

Allocations

In order to apply the reduction calculated above, the average annual *E. coli* load had to be allocated to each of the four non-point sources identified in the BST analysis. Table 13 shows the distribution of the average annual *E. coli* load among sources (derived by multiplying the average annual load by the BST source percent for each of the four source groups), the reduction applied to each source, and the allowable loading for each source. Theoretically these reductions would reduce the *E. coli* load to the water quality standard, resulting in zero violations.

Table 13. Average annual load distribution, reduction, and allowable load by source

	Total (cfu/yr)	Human @ 12% (cfu/yr)	Pet @ 39% (cfu/yr)	Livestock @ 28% (cfu/yr)	Wildlife @ 20% (cfu/yr)
Average Annual Load	4.60×10^{15}	5.52×10^{14}	1.79×10^{15}	1.29×10^{15}	9.20×10^{14}
Reduction	97.00%	99%	99%	99%	88.91%
Target Annual Load/TMDL	1.38×10^{14}	5.52×10^{12}	1.79×10^{13}	1.29×10^{13}	1.02×10^{14}

7.1. Consideration of Critical Conditions

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Tuckahoe Creek is protected during times when conditions are most conducive for water quality criteria exceedances.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken to meet water quality standards. The sources of bacteria for Tuckahoe Creek are a mixture of dry and wet weather driven sources. TMDL development utilizing the load-duration approach applies to the full range of flow conditions; therefore, the critical conditions for Tuckahoe Creek were addressed during TMDL development.

7.2. Consideration of Seasonal Variations

Seasonal variations involve changes in stream flow and water quality as a result of hydrologic and climatological patterns. The load-duration approach allows the pattern of water quality exceedances to be examined for seasonal variations. The load-duration method used to develop this TMDL implicitly incorporates the seasonal variations of precipitation and runoff by looking at the highest water quality violation and applying it to the entire stream flow record when calculating the TMDL.

8.0 TMDL Implementation and Reasonable Assurance

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on Tuckahoe Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at <http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf>. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

8.1 Staged Implementation

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

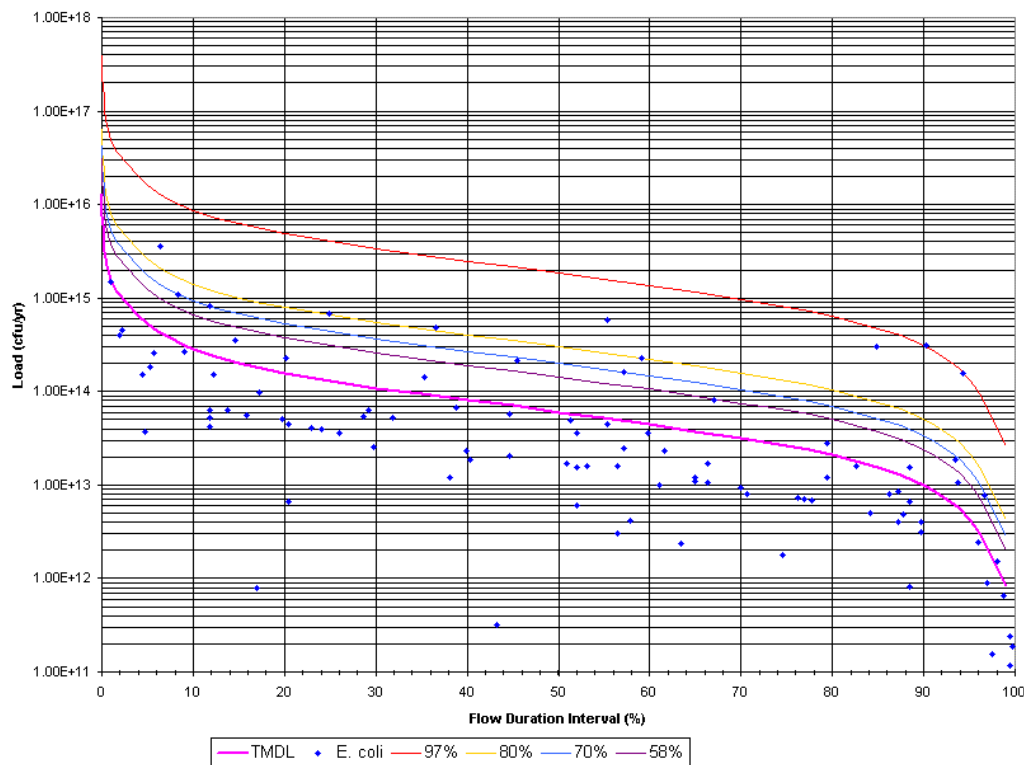
Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

8.2. Stage 1 scenarios

The goal of the stage 1 scenarios is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that violations of the single sample maximum criterion (235 cfu/100mL) are less than 10.5 percent. The stage 1 scenarios were generated with the same model setup as was used for the TMDL allocation scenarios. A margin of safety was not used in determining the stage 1 scenarios.

As stated in Section 7 the TMDL requires a 97% reduction in non-point source loading in order to attain a 0% violation of water quality standards. In order to evaluate interim reduction goals for a phased implementation plan, several reduction levels and their associated violation rates were assessed. Reduction curves for 80%, 70%, and 58% reductions, similar to the max exceedance/reduction curve of Figure 9, were plotted on the Tuckahoe Creek load-duration curve. These reduction curves are presented in Figure 11.

Figure 11. Load duration curve illustrating the TMDL and reduction curves for Tuckahoe Creek at station 2-TKO004.69



The theoretical violation rates for the various load reductions presented in Figure 14 are shown below in Table 14. These were calculated by dividing the number of *E. coli* load datapoints above each respective % reduction curve by the total number of *E. coli* load datapoints (103). Numerous datapoints appear very close to various load reduction lines. The two datapoints appearing on the 80% reduction line at 37% and 59% flow intervals are violations above the 80% line. The datapoint appearing on the 80% reduction line at the 25% flow interval is on the 80% line and is not a violation. The datapoint appearing on the 58% reduction line at a 67% flow interval is below the 58% line and is not a violation.

Table 14. Load Reductions and WQS Violation Rates

Load Reduction	Violation Rate
97%	0%
80%	6.8%
70%	8.8%
58%	13.6%

Based on the reduction analysis presented above and a goal of 10% or fewer violations of the water quality standard, a suitable Phase I reduction level goal would be 70%. Table 15 presents the Phase I load allocations based on a 70% reduction of in-stream loads.

Table 15. Phase I Load Allocations (based on a 70% reduction)

	Total (cfu/yr)	Human @ 12% (cfu/yr)	Pet @ 39% (cfu/yr)	Livestock @ 28% (cfu/yr)	Wildlife @ 20% (cfu/yr)
Average Annual Load	4.60×10^{15}	5.52×10^{14}	1.79×10^{15}	1.29×10^{15}	9.20×10^{14}
Reduction	70%	98%	95%	72%	0%
Allowable Annual Load	1.38×10^{15}	1.10×10^{13}	8.95×10^{13}	3.61×10^{14}	9.20×10^{14}

Often in bacterial TMDL calculations, the wildlife annual load is greater than the total allowable annual load. This did not occur in Tuckahoe Creek calculations. Therefore Phase I scenario load reduction percentages could be proposed for human, pet and livestock contributions. This phase I scenario proposes a 98% reduction in the human *E. coli* load, a 95% reduction in the pet *E. coli* load, and a 72% reduction in the livestock *E. coli* load.

In order to provide some insight into the nature of the Tuckahoe Creek water quality violations and to better target possible BMPs, the correlation between violations, stream flow change, and local precipitation was examined. Results suggest that as many as 100 percent of the violations could be related to runoff events. This suggests that a large majority of the *E. coli* violations may be caused by non-point source runoff events. This also suggests that there was little difference in using a close-by gage versus a distant gage for flow comparisons. Additional information regarding the nature of the violation can be gleaned from looking at the flow conditions under which the violations occur. Six of the violations occur during high or transitional flows. Seven of the violations occur in normal flows. Eight violations occur in low flows, including the maximum violation resulting in the 97% *E. coli* load reduction. The complete analysis is presented in Appendix E.

BMPs effective in correcting dry weather/low-flow violations of the bacteria water quality standard typically include: streamside fencing for cattle exclusion, straight pipe replacement, and septic system repair. Among some of the BMPs effective in reducing bacteria runoff from precipitation events include: riparian buffers zone, retention ponds/basins, range and pasture management, and animal waste management. Detailed lists of BMPs and their relative effectiveness will be presented in the eventual TMDL implementation plan for the Tuckahoe Creek watershed.

Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. A new tributary strategy is currently being developed for the James River Basin to address the nutrient and sediment reductions required to restore the health of the Chesapeake Bay. BMPs for these pollutants will also reduce non-point source bacterial loads. Up-to-date information can be found at the tributary strategy web site under <http://www.naturalresources.virginia.gov/Initiatives/TributaryStrategies/James.cfm>.

8.3 Reasonable Assurance for Implementation

8.3.1 Follow-Up Monitoring

VADEQ will continue monitoring 2-TKO004.69 in accordance with its ambient watershed monitoring program to evaluate reductions in fecal bacteria counts and the effectiveness of TMDL implementation in attainment of water quality standards. This station will be monitored for a two-year cycle, occurring every six years. Station 2-TKO004.69 is currently being monitored through June 2004. The next ambient watershed monitoring cycle for Tuckahoe Creek begins on July 1, 2009 for two years on a bi-monthly basis.

8.3.2 Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

8.3.3. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might

support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

8.3.4. Stormwater Permits

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is the Virginia Pollutant Discharge Elimination System (VPDES) Permit Regulation (9 VAC 25-31-10 et seq.) regarding municipal separate storm sewer systems (MS-4s). Section 9 VAC 25-31-120 describes the requirements for storm water discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of “Best management practices to control or abate the discharge of pollutants when:...(2) Numeric effluent limitations are infeasible,...”.

The entire Tuckahoe Creek watershed is covered by Phase II VPDES permit VA0088617 for the municipal separate storm sewer system (MS-4) owned by the County of Henrico. This permit was issued on March 18, 2003. The effective period of coverage is March 18, 2003 to March 18, 2008. The permits state, under Part II.A., that the “permittee must develop, implement, and enforce a storm water management program designed to reduce the discharge of pollutants from the MS4 to the maximum extent practicable (MEP), to protect water quality, and to satisfy the appropriate water quality requirements of the Clean Water Act and the State Water Control Law.”

The permit also contains a TMDL clause that states: “If a TMDL is approved for any waterbody into which the small MS4 discharges, the Board will review the TMDL to determine whether the TMDL includes requirements for control of storm water discharges. If discharges from the MS4 are not meeting the TMDL allocations, the Board will notify the permittee of that finding and may require that the Storm Water Management Program required in Part II be modified to implement the TMDL within a timeframe consistent with the TMDL.”

For MS4/VPDES general permits, DEQ expects revisions to the permittee’s Stormwater Pollution Prevention Plans to specifically address the TMDL pollutants of concern. DEQ anticipates that BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its BMPs to achieve the TMDL reductions. However, only failing to implement the required BMPs would be considered a violation of the permit. DEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacteria TMDLs (see section 8.3.5.below). At some future time, it may therefore become necessary to investigate the stream’s use designation and adjust the water quality criteria through a Use Attainability Analysis. Any changes to the TMDL resulting from water quality standards change on Bailey Creek would be reflected in the permittee’s Stormwater Pollution Prevention Plan required by the MS4/VPDES permit.

Additional information on Virginia’s Storm Water Phase 2 program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at <http://www.deq.virginia.gov/vpdes/stormwater.html>.

8.3.5 Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. These streams may not be able to attain standards without some reduction in wildlife load. **Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards.** While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia has proposed (during its recent triennial water quality standards review) a new “secondary contact” category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for “secondary contact recreation” which means “a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)”. These new criteria will become effective pending EPA approval and can be found at <http://www.deq.virginia.gov/wqs/rule.html>.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process.

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in section 8.1 above. DEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

9. Public Participation

The development of the Tuckahoe Creek TMDL was not possible without public participation. A Technical Advisory Committee meeting was held at the Piedmont Regional Office training room in Glen Allen, VA at 2 pm on January 14, 2004. A public meeting was held at the Piedmont Regional Office of DEQ, 4949-A Cox Road, Glen Allen, VA. at 7 pm on January 20, 2004 to discuss the process for TMDL development and the source assessment input for Tuckahoe Creek. Twelve people attended the public meeting. Copies of the presentation materials were available for public distribution. The public meeting was public noticed in the Virginia Register. There was a 30 day-public comment period after the public meeting. Four questions were asked at the public meeting, and two written comments were mailed to DEQ. These questions, comments and responses are submitted to EPA separately from this document.

10. References

- APPMA (American Pet Products Manufacturers Association) 2001-2002 National Pet Owners Survey. <http://www.hsus.org/ace/11831> (Accessed 11/06/02)
- Geldreich E. E. Bacterial populations and indicator concepts in feces, sewage, stormwater and solid wastes. In *Indicators of Viruses in Water and Food* (Edited by Berg G.). Ann Arbor Science, Ann Arbor, Mich. 1978.
- Hagedorn, C., Virginia Tech, http://soils1.cses.vt.edu/ch/biol_4684/bst/BST.html 2002. (Accessed 12/31/02)
- ICPRB (Interstate Commission on the Potomac River), *Bacteria TMDLs for the Goose Creek Watershed*, Virginia, 2002.
- MapTech. *Fecal Coliform TMDL (Total Maximum Daily Load) Development for Catoctin Creek Impairments*. Virginia, 2002.
- MapTech. *Fecal Coliform TMDL (Total Maximum Daily Load) Development for Gills Creek Impairments*. Virginia, 2002.
- Reneau, R.B. Jr. 2000 Crop and Soil Environmental Sciences. Virginia Tech. Personal communication. January 7, 2000.
- SAIC (Science Applications International Corporation). *Fecal Coliform TMDL (Total Maximum Daily Load) Development for Holmans Creek, Virginia*. Reston, Virginia. 2001.
- Simpson, J.; Santo Domingo, J.; Reasoner, D. *Env. Science & Technology*. **2002**, 36, 5279-5287.
- SRCC (Southeast Regional Climate Center) http://www.dnr.state.sc.us/climate/sercc/products/historical/historical_va.html (Accessed 12/18/02)
- USDA - National Agricultural Statistics Service. 1997 Census of Agriculture, for Henrico County, Virginia. Volume 1. 1999.
- USDA - Natural Resources Conservation Service (NRCS) Soil Survey Division. Official Soil Series Description. <http://ortho.ftw.nrcs.usda.gov/cgi-bin/osd/osdname.cgi> (Accessed 12/22/03)
- USEPA (U. S. Environmental Protection Agency), Total Maximum Daily Load Guidance. 1991.
- VADCR (Virginia Department of Conservation and Recreation), 2003 Spreadsheet of Animal Fecal Production Rates and Fecal Coliform Densities. William Keeling.
- VADEQ (Virginia Department of Environmental Quality), 2002 303(d) Report on Impaired Waters.
- VADEQ (Virginia Department of Environmental Quality), 1998 303(d) Total Maximum Daily Load Priority List and Report.
- VADEQ (Virginia Department of Environmental Quality), Lynnhaven Bay, Broad and Linkhorn Bay Total Maximum Daily Load (TMDL) Report for Shellfish Areas Listed for Bacteria Contamination, Virginia, 2003.
- Yagow, G. Virginia Tech Department of Bacterial Systems Engineering, Personal telecommunication, 2003.

Appendix A

Glossary

GLOSSARY

Note: All entries in italics are taken from USEPA (1998). All non-italicized entries are taken from MapTech (2002).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)

Ambient water quality. Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.

Anthropogenic. Pertains to the [environmental] influence of human activities.

Antidegradation Policies. Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.

Background levels. Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.

Bacteria. Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Best management practices (BMPs). Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants.

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is section 303(d), which establishes the TMDL program.*

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Confluence. *The point at which a river and its tributary flow together.*

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge permits (under NPDES). *A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established*

under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Existing use. *Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earth's surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

Hydrograph. *A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle. *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology. *The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Isolate. *An inbreeding biological population that is isolated from similar populations by physical or other means.*

Limits (upper and lower). *The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.*

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving water's loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the*

receiving waterbody (CWA section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).

Mathematical model. *A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Non-point source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Numeric targets. *A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Peak runoff. *The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

Permit. *An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Phased approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a Federal Register notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Raw sewage. *Untreated municipal sewage.*

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Stakeholder. *Any person with a vested interest in the TMDL development.*

Standard. *In reference to water quality (e.g. 200 cfu/100 ml geometric mean limit).*

Storm runoff. *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream restoration. Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.

Surface area. The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.

Surface runoff. Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.

Surface water. All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.

Topography. The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.

Total Maximum Daily Load (TMDL). The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Transport of pollutants (in water). Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.

Tributary. A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

DACS. Department of Agriculture and Consumer Services.

DCR. Department of Conservation and Recreation.

DEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also **Domestic wastewater**.*

Wastewater treatment. *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality. *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality criteria. *Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

Appendix B
Antibiotic Resistance Analysis
(MapTech)

When performing ARA, isolates (colonies picked from membrane filtration plates) of *E. coli* or *Enterococcus* are transferred to a 96-well tissue culture plate (one isolate per well) containing a selective liquid medium. The 96-well plates are incubated and confirmed as *E. coli* or

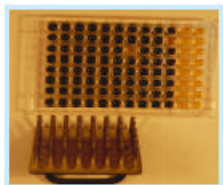


Figure 1. 96-well plate after incubation.

Enterococcus by color changes in the liquid after incubation (Figure 1). Antibiotic stock solutions are prepared and each of twenty-eight or more antibiotic/concentrations is added separately to flasks of autoclaved and cooled Trypticase Soy Agar (TSA) from the stock solutions to achieve the desired concentration, and then poured into sterile 15x100mm petri dishes.

Control plates (no antibiotics) are included with each set. Isolates are transferred from the 96-well plate using a stainless steel 48-prong replica plater (Sigma). The replicator is flame-sterilized (95% ethanol) after inoculation of each TSA plate. Resistance to an antibiotic is determined by comparing each isolate to the growth of that isolate on the control plate. A one (1) is recorded for growth and a zero (0) is recorded for no growth (Figure 2). This is repeated for each isolate on each of the 30 antibiotic plates to develop a profile.

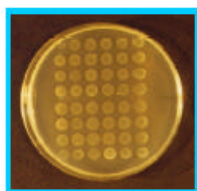


Figure 2. TSA control plate (with no antibiotics) showing growth of all 48 isolates.

The profile is then compared against the known source library to determine the source of the isolate (see data analysis section). The basic process is the same for all approaches, that is, a data base of known sources analyzed using the BST method of choice must be developed and samples of unknown bacterial origin are collected, analyzed and compared to the known source database. For studies, such as Total Maximum Daily Loads (TMDL), we recommend the ARA procedure due to typical cost constraints. Typically we analyze 24 isolates per unknown source (e.g. stream or well water) sample. This provides measurements of the proportion of a given source that are in increments of approximately 4%. If more precision is required, 48 isolates can be analyzed, resulting in resolution of approximately 2%. If the sampling is to be done in a geographical area where a database of known sources has not been developed, we will need to collect samples from known sources (i.e. human, livestock, wildlife) and compare them to our existing databases to determine if one of our existing databases is compatible with the study area. Twenty-four isolates from each of these samples will be analyzed. If no existing database is compatible, we will need to develop a database for the study area. The number of samples needed depend on variability of source samples. We have had a good deal of success in the past by using existing databases through obtaining known source samples from each group (i.e. human, livestock, wildlife) in the study area and comparing them to existing databases.

Appendix C

Calculations

Calculations

Point Source waste load calculation from Section 5.2.

For Henrico WTP, permitted discharge concentration (126 cfu/100 ml) * design flow (0.70 MGD) * 1000000 g/MGD * 3.7853 L/g * 1000 mL/L / 100 mL cfu * 365 d / yr

For Henrico MS4:

Low Intensity Residential = 5555 acres x 20% imperviousness = 1111 impervious acres

High Intensity Residential = 1.1 acres x 50% imperviousness = 0.55 impervious acres

High Intensity Commercial / Industrial = 2531.1 acres x 70% imperviousness = 1771.77 impervious acres

Total Tuckahoe watershed impervious acres = 1111 ac + 0.55 ac + 1771.77 ac = 2883.32 impervious ac.

Tuckahoe impervious acres 2883.32 ac / Total Tuckahoe acres 41176.4 ac = 7.0 % Total Tuckahoe watershed imperviousness

Total Tuckahoe watershed 7.0% imperviousness X TMDL allowable load from Section 6.2, 1.50×10^{14} cfu/yr = **1.05×10^{13} cfu/yr Henrico MS4 wasteload allocation**

Allowable Load Calculation from Section 6.14.

TMDL cfu/yr = Avg annual Q ft³/s * 7.48 gal/ft³ * 3.785 l/gal * 1000 ml/l * 235 cfu/100 ml * 60 s/min * 60 min/day * 24 hrs/day * 365 days/yr,

Or TMDL cfu/yr = Avg annual Q ft³/s * $2.098176173 \times 10^{14}$

Where:

TMDL cfu/yr = Allowable load in cfu/yr

235 cfu/100 ml = Instantaneous *E. coli* standard

Average annual Q ft³/s = Average annual flow in cubic feet per second

cfu = *E. coli* colony forming units.

l = liters

ml = milliliters

s = seconds

min = minutes

yr = year

gal = gallons

Required Reduction Calculation from Section 7.

TMDL cfu/yr = LA cfu/yr + WLA cfu/yr + MOS (cfu/yr)

OL = LA cfu/yr + WLA cfu/yr

% reduction = [(OL - TMDL)/OL] * 100

Where:

TMDL = total maximum daily load

LA = load allocation

WLA = waste load allocation

MOS = margin of safety

OL = observed load (= **average annual load**)

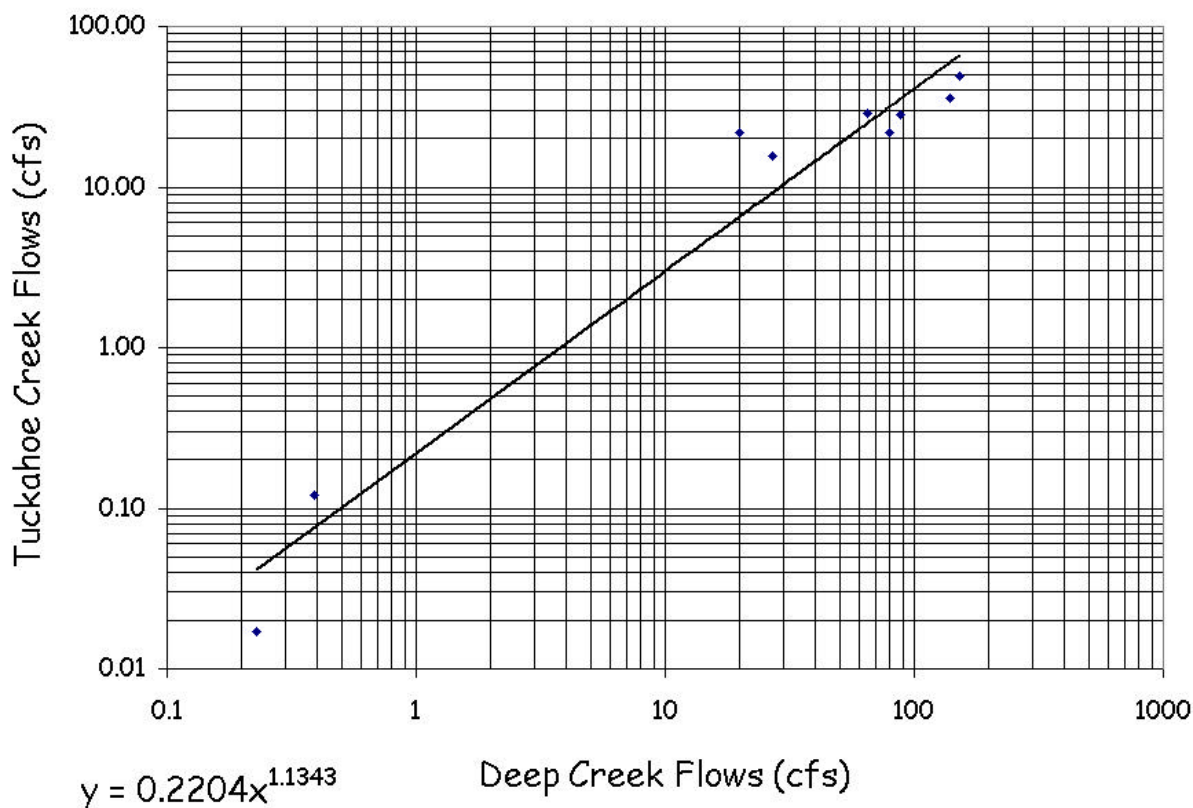
Appendix D
Reference Stream Selection

Once several possible reference watersheds are selected, a correlation analysis is performed on the flow measurements of the reference and target gauges. Usually the reference gauge with the strongest correlation to the target gauge is selected; however, the final decision is subject to best professional judgement. In some cases a watershed with a lower correlation may be a better choice.

The reference stream correlation is performed by entering the flow measurement data from the target stream (Tuckahoe Creek) into an Excel spreadsheet along with daily mean flow data from the reference streams. The Excel "Correlation" data analysis tool is then run to determine "R" or the Pearson's correlation coefficient which can be used as an indication of the strength of the correlation. In this analysis absolute values of the Pearson's coefficient between 0-0.19 were regarded as indicating a very weak correlation, 0.2-0.39 as weak, 0.40-0.59 as moderate, 0.6-0.79 as strong and 0.8-1 as a very strong correlation.

Using the Excel graphing package, the measurement data from Tuckahoe Creek were plotted against the corresponding daily mean flow data for the Deep Creek gage. Excel was then used to draw a best-fit line through the data points and develop the equation for the "regression" line. Using the equation for the regression line, daily mean flow values from Deep Creek could be plugged into the "x" or independent variable in the equation and the flow at the Tuckahoe Creek site, the "y" or dependent variable, could be calculated.

Flow Regression for Tuckahoe Creek & Deep Creek



Appendix E
Flow Change and Precipitation Analysis

In order to better target BMPs for the Tuckahoe Creek watershed, the correlation between water quality violations, stream flow changes and precipitation was investigated. The goal was to determine which violations might be related to runoff and which might be related to direct deposition.

As stated in Section 6.1 on flow data, there was no continuous stream gage in the Tuckahoe Creek watershed, so there is little historic flow data. For this reason, the continuous gage at Deep Creek near Mannboro (station 02041000) was used to develop the flow duration curve for Tuckahoe Creek. When assessing the correlation between flow change and violations it was flow changes at the Fine Creek gage that were examined, because it was closest to Tuckahoe Creek at 10 miles west. Flow changes at the Deep Creek gage were also used because Deep Creek was the most accurate high flow correlation with Tuckahoe Creek. The theory is that flow changes at the Fine Creek and/or the Deep Creek gages would reflect flow changes in Tuckahoe Creek. Changes in flow might, in turn, signify runoff from precipitation events.

To assess the link between flow changes and precipitation events, precipitation records from the Ashland, VA weather station, located 13 miles northeast of the center of the Tuckahoe Creek watershed, were examined. Precipitation events on the 4 days preceding, and on the day of each violation were examined. Precipitation events on the 4 days before the violation were examined to see if decreasing flows on violation days were the result of a precipitation event within the preceding 96 hours.

Results of the study are presented in Table A.E.1. below.

Table A.E.1. PRECIP / E coli Violation / Flow comparison - Tuckahoe Creek

Sampling Date	Fecal Coliform Analytical Result (cfu/100 mL)	Translated E. coli Value (cfu/100 mL)	Target Stream Flow (cfs)	Duration Interval (percentile as a number)	Annualized E. coli Load (cfu/yr)	Fine Creek target flow increase or receding from peak	Deep Creek target flow increase or receding from peak	Ashland, VA Same Day Rain	Ashland, VA 4 Day Previous Rain
4/27/92	2400	1263	42.77	37	4.82E+14	Y	Y	0.01	0.34
10/13/93	800	460	2.60	94	1.07E+13	Y	Y	0	0.74
7/20/94	9200	4343	7.72	85	3.00E+14	Y	Y	0	0.84
10/24/94	1300	719	33.11	46	2.13E+14	Y	Y	0	1.09
7/20/95	2200	1166	22.05	59	2.30E+14	Y	Y	0	0.23
4/2/96	1400	770	156.30	8	1.07E+15	Y	Y	0.15	1.12
7/10/96	16000	7221	4.76	90	3.07E+14	N	Y	0	0.11
8/20/97	16000	7221	2.40	94	1.55E+14	Y	Y	1.22	0
9/18/97	1400	770	2.73	94	1.88E+13	Y	Y	0.02	0
10/30/97	950	539	16.95	67	8.16E+13	Y	Y	0	0.64
4/23/98	700	407	98.50	15	3.58E+14	Y	Y	0.02	0.34
6/15/98	5400	2661	24.66	55	5.86E+14	Y	Y	0.77	0.47
7/28/99	1100	617	1.40	97	7.70E+12	Y	Y	0	0
9/15/99	490	293	5.85	88	1.53E+13	Y	Y	0.53	0
6/13/00	500	299	10.44	79	2.79E+13	Y	Y	0	0
2/21/01	600	353	44.64	35	1.41E+14	Y	Y	0	0.67
10/16/02 Actual E. coli		780	23.35	57	1.63E+14	Y	Y	1.48	0.14
11/12/02 Actual E. coli		1200	62.84	25	6.73E+14	Y	Y	1.3	1.27
4/7/03 Actual E. coli		2000	199.36	6	3.56E+15	Y	Y	1.8	0

6/17/03 Actual <i>E. coli</i>	340	75.18	20	2.28E+14	Y	Y	1	0.85
12/11/03 Actual <i>E. coli</i>	800	116.71	12	8.34E+14	NA	NA	0	1.7

The results of the study suggest that comparing to Fine Creek 10 miles west or to Deep Creek 25 miles WSW as many as 100 percent of the violations could be related to runoff events. This suggests that a large majority of the *E. coli* violations may be caused by non-point source runoff events. This also suggests that there was little difference in using a close-by gage versus a distant gage for flow comparisons.

Additional information regarding the nature of the violation can be gleaned from looking at the flow conditions under which the violations occur. Six of the violations occur during high or transitional flows. Seven of the violations occur in normal flows. Eight violations occur in low flows, including the maximum violation resulting in the 97% *E. coli* load reduction.

Appendix F

TMDL Scenario with WLA increased by a factor of 5

The following tables represent a TMDL scenario where the WLA for the point source discharger has been increased by a factor of five, and the MS4 WLA has been added to that expanded total. The scenario was presented to the public and is intended to be appended to the TMDL report. The expanded WLA for the Tuckahoe Creek watershed represents approximately 11.8 percent of the TMDL annual average, and a 41.9 percent increase in the original WLA. The expanded WLA results in a 3.6 percent decrease in the NPS load allocation.

Table A. Average annual *E. coli* loads and TMDL for Tuckahoe Creek watershed (cfu/yr)

WLA ¹	LA	MOS	TMDL
1.66×10^{13}	1.33×10^{14}	(implicit)	1.50×10^{14}

¹The point sources permitted to discharge in the Tuckahoe Creek watershed are presented in section 5.2.

Table B. TMDL and required reduction for Tuckahoe Creek

Allowable Loads (cfu/yr)		Average Annual EC Load (cfu/yr)	Required Reduction
TMDL annual average	1.50×10^{14}		
Wasteload Allocation (WLA)	1.66×10^{13}		
MOS	(implicit)		
Load Allocation	1.33×10^{14}	4.60×10^{15}	97.11%

Table C. Average annual load distribution, reduction, and allowable load by source

	Total (cfu/yr)	Human @ 12% (cfu/yr)	Pet @ 39% (cfu/yr)	Livestock @ 28% (cfu/yr)	Wildlife @ 20% (cfu/yr)
Average Annual Load	4.60×10^{15}	5.52×10^{14}	1.79×10^{15}	1.29×10^{15}	9.20×10^{14}
Reduction	97.11%	99%	99%	99%	89.49%
Target Annual Load/TMDL	1.33×10^{14}	5.52×10^{12}	1.79×10^{13}	1.29×10^{13}	9.67×10^{13}